THE ECONOMY

OF

WORKSHOP MANIPULATION.

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A LOGICAL METHOD OF LEARNING CONSTRUCTIVE MECHANICS.

ARRANGED WITH QUESTIONS

FOR THE USE OF

APPRENTICE ENGINEERS AND STUDENTS.

BY

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PREFACE.

The contents of the present work, except the Introduction and the chapter on Gauges, consist mainly in a revision of a series of articles published in "Engineering" and the Journal of the Franklin Institute, under the head of "The Principles of Shop Manipulation," during 1873 and 1874.

The articles alluded to were suggested by observations made in actual practice, and by noting a "habit of thought" common among learners, which did not seem to accord with the purely scientific manner in which mechanical subjects are now so constantly treated.

The favourable reception which the articles on "Shop Manipulation" met with during their serial publication, and various requests for their reproduction in the form of a book, has led to the present edition.

The addition of a few questions at the end of each chapter, some of which are not answered in the text, it is thought will assist the main object of the work, which is to promote a habit of logical investigation on the part of learners.

It will be proper to mention here, what will be more fully pointed out in the Introduction, that although workshop processes may be scientifically explained and proved, they must nevertheless be learned logically. This view, it is hoped, will not lead to anything in the book being construed as a disparagement of the importance of theoretical studies.

Success in Technical Training, as in other kinds of education, must depend greatly upon how well the general mode of thought among learners is understood and followed; and if the present work directs some attention to this matter it will not fail to add something to those influences which tend to build up our industrial interests.

J. R.

10 John Street, Adelphi,
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INTRODUCTION.

In adding another to the large number of books which treat upon Mechanics, and especially of that class devoted to what is called Mechanical Engineering, it will be proper to explain some of the reasons for preparing the present work; and as these explanations will constitute a part of the work itself, and be directed to a subject of some interest to a learner, they are included in the Introduction.

First I will notice that among our many books upon mechanical subjects there are none that seem to be directed to the instruction of apprentice engineers; at least, there are none directed to that part of a mechanical education most difficult to acquire, a power of analysing and deducing conclusions from commonplace matters.

Our text-books, such as are available for apprentices, consist mainly of mathematical formulæ relating to forces, the properties of material, examples of practice, and so on, but do not deal with the operation of machines nor with constructive manipulation, leaving out that most important part of a mechanical education, which consists in special as distinguished from general knowledge.

The theorems, formulæ, constants, tables, and rules, which are generally termed the principles of mechanics, are in a sense only symbols of principles; and it is possible, as many facts will prove, for a learner to master the theories and symbols of

mechanical principles, and yet not be able to turn such knowledge to practical account.

A principle in mechanics may be known, and even familiar to a learner, without being logically understood; it might even be said that both theory and practice may be learned without the power to connect and apply the two things. A person may, for example, understand the geometry of tooth gearing and how to lay out teeth of the proper form for various kinds of wheels, how to proportion and arrange the spokes, rims, hubs, and so on; he may also understand the practical application of wheels as a means of varying or transmitting motion, but between this knowledge and a complete wheel lies a long train of intricate processes, such as pattern-making, moulding, casting, boring, and fitting. Farther on comes other conditions connected with the operation of wheels, such as adaptation, wear, noise, accidental strains, with many other things equally as important, as epicycloidal curves or other geometrical problems relating to wheels.

Text-books, such as relate to construction, consist generally of examples, drawings, and explanations of machines, gearing, tools, and so on; such examples are of use to a learner, no doubt, but in most cases he can examine the machines themselves, and on entering a shop is brought at once in contact not only with the machines but also with their operation. Examples and drawings relate to *how* machines are constructed, but when a learner comes to the actual operation of machines, a new and more interesting problem is reached in the reasons *why* they are so constructed.

The difference between *how* machinery is constructed and *why* it is so constructed, is a wide one. This difference the reader should keep in mind, because it is to the second query that the present work will be mainly addressed. There will be an attempt—an imperfect one, no doubt, in some cases—to deduce from practice the causes which have led to certain forms of machines, and to the ordinary processes of workshop manipulation. In the mind of a learner, whether apprentice or student, the strongest tendency is to investigate why certain proportions and arrangement are right and others wrong—why the operations of a workshop are conducted in one manner instead of another? This is the natural habit of thought, and the natural course of inquiry and investigation is deductive.

Nothing can be more unreasonable than to expect an apprentice

engineer to begin by an inductive course in learning and reasoning about mechanics. Even if the mind were capable of such a course, which can not be assumed in so intricate and extensive a subject as mechanics, there would be a want of interest and an absence of apparent purpose which would hinder or prevent progress. Any rational view of the matter, together with as many facts as can be cited, will all point to the conclusion that apprentices must learn deductively, and that some practice should accompany or precede theoretical studies. How dull and objectless it seems to a young man when he toils through "the sum of the squares of the base and perpendicular of a right-angle triangle," without knowing a purpose to which this problem is to be applied; he generally wonders why such puzzling theorems were ever invented, and what they can have to do with the practical affairs of life. But if the same learner were to happen upon a builder squaring a foundation by means of the rule "six, eight, and ten," and should in this operation detect the application of that tiresome problem of "the sum of the squares," he would at once awake to a new interest in the matter; what was before tedious and without object, would now appear useful and interesting. The subject would become fascinating, and the learner would go on with a new zeal to trace out the connection between practice and other problems of the kind. Nothing inspires a learner so much as contact with practice; the natural tendency, as before said, is to proceed deductively.

A few years ago, or even at the present time, many schoolbooks in use which treat of mechanics in connection with natural philosophy are so arranged as to hinder a learner from grasping a true conception of force, power, and motion; these elements were confounded with various agents of transmission, such as wheels, wedges, levers, screws, and so on. A learner was taught to call these things "mechanical powers," whatever that may mean, and to compute their power as mechanical elements. In this manner was fixed in the mind, as many can bear witness, an erroneous conception of the relations between power and the means for its transmission; the two things were confounded together, so that years, and often a lifetime, has not served to get rid of the idea of power and mechanism being the same. To such teaching can be traced nearly all the crude ideas of mechanics so often met with among those well informed in other matters. In the great change from empirical rules to proved constants, from

special and experimental knowledge to the application of science in the mechanic arts, we may, however, go too far. The incentives to substitute general for special knowledge are so many, that it may lead us to forget or underrate that part which cannot come within general rules.

The labour, dirt, and self-denial inseparable from the acquirement of special knowledge in the mechanic arts are strong reasons for augmenting the importance and completeness of theoretical knowledge, and while it should be, as it is, the constant object to bring everything, even manipulative processes, so far as possible, within general rules, it must not be forgotten that there is a limit in this direction.

In England and America the evils which arise from a false or over estimate of mere theoretical knowledge have thus far been avoided. Our workshops are yet, and must long remain, our technological schools. The money value of bare theoretical training is so fast declining that we may be said to have passed the point of reaction, and that the importance of sound practical knowledge is beginning to be more felt than it was some years ago. It is only in those countries where actual manufactures and other practical tests are wanting, that any serious mistake can be made as to what should constitute an education in mechanics. Our workshops, if other means fail, will fix such a standard; and it is encouraging to find here and there among the outcry for technical training, a note of warning as to the means to be employed.

During the meeting of the British Association in Belfast (1874), the committee appointed to investigate the means of teaching Physical Science, reported that "the most serious obstacle discovered was an absence from the minds of the pupils of a firm and clear grasp of the concrete facts forming a base of the reasoning processes they are called upon to study; and that the use of text-books should be made subordinate to an attendance upon lectures and demonstrations."

Here, in reference to teaching science, and by an authority which should command our highest confidence, we have a clear exposition of the conditions which surround mechanical training, with, however, this difference, that in the latter "demonstration" has its greatest importance.

Professor John Sweet of Cornell University, in America, while delivering an address to the mechanical engineering classes,

during the same year, made use of the following words: "It is not what you 'know' that you will be paid for; it is what you can 'perform,' that must measure the value of what you learn here." These few words contain a truth which deserve to be earnestly considered by every student engineer or apprentice; as a maxim it will come forth and apply to nearly everything in subsequent practice.

I now come to speak directly of the present work and its objects. It may be claimed that a book can go no further in treating of mechanical manipulation than principles or rules will reach, and that books must of necessity be confined to what may be called generalities. This is in a sense true, and it is, indeed, a most difficult matter to treat of machine operations and shop processes; but the reason is that machine operations and shop processes have not been reduced to principles or treated in the same way as strains, proportions, the properties of material, and so on. I do not claim that manipulative processes can be so generalised—this would be impossible; yet much can be done, and many things regarded as matters of special knowledge can be presented in a way to come within principles, and thus rendered capable of logical investigation.

Writers on mechanical subjects, as a rule, have only theoretical knowledge, and consequently seldom deal with workshop processes. Practical engineers who have passed through a successful experience and gained that knowledge which is most difficult for apprentices to acquire, have generally neither inclination nor incentives to write books. The changes in manipulation are so frequent, and the operations so diversified, that practical men have a dread of the criticisms which such changes and the differences of opinion may bring forth; to this may be added, that to become a practical mechanical engineer consumes too great a share of one's life to leave time for other qualifications required in preparing books. For these reasons "manipulation" has been neglected, and for the same reasons must be imperfectly treated here. The purpose is not so much to instruct in shop processes as to point out how they can be best learned, the reader for the most part exercising his own judgment and reasoning powers. It will be attempted to point out how each simple operation is governed by some general principle, and how from such operations, by tracing out the principle which lies at the bottom, it is possible to deduce logical conclusions as to what is right or

wrong, expedient or inexpedient. In this way, it is thought, can be established a closer connection between theory and practice, and a learner be brought to realise that he has only his reasoning powers to rely on; that formulæ, rules, tables, and even books, are only aids to this reasoning power, which alone can master and combine the symbol and the substance.

No computations, drawings, or demonstrations of any kind will be employed to relieve the mind of the reader from the care of remembering and a dependence on his own exertions. Drawings, constants, formulæ, tables, rules, with all that pertains to computation in mechanics, are already furnished in many excellent books, which leave nothing to be added, and such books can be studied at the same time with what is presented here.

The book has been prepared with a full knowledge of the fact, that what an apprentice may learn, as well as the time that is consumed in learning, are both measured by the personal interest felt in the subject studied, and that such a personal interest on the part of an apprentice is essential to permanent success as an engineer. A general dryness and want of interest must in this, as in all cases, be a characteristic of any writing devoted to mechanical subjects: some of the sections will be open to this charge, no doubt, especially in the first part of the book; but it is trusted that the good sense of the reader will prevent him from passing hurriedly over the first part, to see what is said, at the end, of casting, forging, and fitting, and will cause him to read it as it comes, which will in the end be best for the reader, and certainly but fair to the writer.

CHAPTER I.

PLANS OF STUDYING.

By examining the subject of applied mechanics and shop manipulation, a learner may see that the knowledge to be acquired by apprentices can be divided into two departments, that may be called general and special. General knowledge relating to tools, processes and operations, so far as their construction and action may be understood from general principles, and without special

or experimental instruction. Special knowledge is that which is based upon experiment, and can only be acquired by special, as distinguished from general sources.

To make this plainer, the laws of forces, the proportion of parts, strength of material, and so on, are subjects of general knowledge that may be acquired from books, and understood without the aid of an acquaintance with the technical conditions of either the mode of constructing or the manner of operating machines; but how to construct proper patterns for castings, or how the parts of machinery should be moulded, forged, or fitted, is special knowledge, and must have reference to particular cases. The proportions of pulleys, bearings, screws, or other regular details of machinery, may be learned from general rules and principles, but the hand skill that enters into the manufacture of these articles cannot be learned except by observation and experience. The general design, or the disposition of metal in machine-framing, can be to a great extent founded upon rules and constants that have general application; but, as in the case of wheels, the plans of moulding such machine frames are not governed by constant rules or performed in a uniform manner. Patterns of different kinds may be employed; moulds may be made in various ways, and at a greater and less expense; the metal can be mixed to produce a hard or a soft casting, a strong or a weak one; the conditions under which the metal is poured may govern the soundness or shrinkage,—things that are determined by special instead of general conditions.

The importance of a beginner learning to divide what he has to learn into these two departments of special and general, has the advantage of giving system to his plans, and pointing out that part of his education which must be acquired in the workshop and by practical experience. The time and opportunities which might be devoted to learning the technical manipulations of a foundry, for instance, would be improperly spent if devoted to metallurgic chemistry, because the latter may be studied apart from practical foundry manipulation, and without the opportunity of observing casting operations.

It may also be remarked that the special knowledge involved in applied mechanics is mainly to be gathered and retained by personal observation and memory, and that this part is the greater one; all the formulæ relating to machine construction may be learned in a shorter time than is required to master and

understand the operations which may be performed on an engine lathe. Hence first lessons, learned when the mind is interested and active, should as far as possible include whatever is special; in short, no opportunity of learning special manipulation should be lost. If a wheel pattern come under notice, examine the mannre in which it is framed together, the amount of draught, and how it is moulded, as well as to determine whether the teeth have true cycloidal curves.

Once, nearly all mechanical knowledge was of the class termed special, and shop manipulations were governed by empirical rules and the arbitrary opinions of the skilled; an apprentice entered a shop to learn a number of mysterious operations, which could not be defined upon principles, and only understood by special practice and experiment. The arrangement and proportions of mechanism were also determined by the opinions of the skilled, and like the manipulation of the shop, were often hid from the apprentice, and what he carried in his memory at the end of an apprenticeship was all that he had gained. The tendency of this was to elevate those who were the fortunate possessors of a strong natural capacity, and to depress the position of those less fortunate in the matter of mechanical "genius," as it was called. The ability to prepare proper designs, and to succeed in original plans, was attributed to a kind of intuitive faculty of the mind; in short, the mechanic arts were fifty years ago surrounded by a superstition of a different nature, but in its influences the same as superstition in other branches of knowledge.

But now all is changed: natural phenomena have been explained as being but the operation of regular laws; so has mechanical manipulation been explained as consisting in the application of general principles, not yet fully understood, but far enough, so that the apprentice may with a substantial education, good reasoning powers, and determined effort, force his way where once it had to be begged. The amount of special knowledge in mechanical manipulation, that which is irregular and modified by special conditions, is continually growing less as generalisation and improvement go on.

Another matter to be considered is that the engineering apprentice, in estimating what he will have to learn, must not lose sight of the fact that what qualifies an engineer of to-day will fall far short of the standard that another generation will fix, and of that period in which his practice will fall. This I men-

tion because it will have much to do with the conceptions that a learner will form of what he sees around him. To anticipate improvement and change is not only the highest power to which a mechanical engineer can hope to attain, but is the key to his success.

By examining the history of great achievements in the mechanic arts, it will be seen that success has been mainly dependent upon predicting future wants, as well as upon an ability to supply such wants, and that the commercial value of mechanical improvements is often measured by conditions that the improvements themselves anticipate. The invention of machine-made drills, for example, was but a small matter; but the demand that has grown up since, and because of their existence, has rendered this improvement one of great value. Moulded bearings for shafts were also a trifling improvement when first made, but it has since influenced machine construction in America in a way that has given great importance to the invention.

It is generally useless and injudicious to either expect or to search after radical changes or sweeping improvements in machine manufacture or machine application, but it is important in learning how to construct and apply machinery, that the means of foreseeing what is to come in future should at the same time be considered. The attention of a learner can, for example, be directed to the division of labour, improvements in shop system, how and where commercial interests are influenced by machinery, what countries are likely to develop manufactures, the influence of steam-hammers on forging, the more extended use of steel when cheapened by improved processes for producing it, the division of mechanical industry into special branches, what kind of machinery may become staple, such as shafts, pulleys, wheels, and so on. These things are mentioned at random, to indicate what is meant by looking into the future as well as at the present.

Following this subject of future improvement farther, it may be assumed that an engineer who understands the application and operation of some special machine, the principles that govern its movements, the endurance of the wearing surfaces, the direction and measure of the strains, and who also understands the principles of the distribution of material, arrangement, and proportions,—that such an engineer will be able to construct machines, the plans of which will not be materially

departed from so long as the nature of the operations to which the machines are applied remain the same.

A proof of this proposition is furnished in the case of standard machine tools for metal-cutting, a class of machinery that for many years past has received the most thorough attention at the hands of our best mechanical engineers.

Standard tools for turning, drilling, planing, boring, and so on, have been changed but little during twenty years past, and are likely to remain quite the same in future. A lathe or a planing-machine made by a first-class establishment twenty years ago has, in many cases, the same capacity, and is worth nearly as much in value at the present time as machine tools of modern construction—a test that more than any other determines their comparative efficiency and the true value of the improvements that have been made. The plans of the framing for machine tools have been altered, and many improvements in details have been added; yet, upon the whole, it is safe to assume, as before said, that standard tools for metal-cutting have reached a state of improvement that precludes any radical changes in future, so long as the operations in metal-cutting remain the same.

This state of improvement which has been reached in machine-tool manufacture, is not only the result of the skill expended on such tools, but because as a notable exception they are the agents of their own production; that is, machine tools produce machine tools, and a maker should certainly become skilled in the construction of implements which he employs continually in his own business. This peculiarity of machine-tool manufactures is often overlooked by engineers, and unfair comparisons made between machines of this class and those directed to wood conversion and other manufacturing processes, which machinists, as a rule, do not understand.

Noting the causes and conditions which have led to this perfection in machine-tool manufacture, and how far they apply in the case of other classes of machinery, will in a measure indicate the probable improvements and changes that the future will produce.

The functions and adaptations of machinery constitute, as already explained, the science of mechanical engineering. The functions of a machine are a foundation on which its plans are based; hence machine functions and machine effect are

matters to which the attention of an apprentice should first be directed.

In the class of mechanical knowledge that has been defined as general, construction comes in the third place: first, machine functions; next, plans or adaptation of machines; and third, the manner of constructing machines. This should be the order of study pursued in learning mechanical manipulation. Instead of studying how drilling-machines, planing-machines or lathes are arranged, and next plans of constructing them, and then the principles of their operation, which is the usual course, the learner should reverse the order, studying, first, drilling, planing, and turning as operations; next, the adaptation of tools for the purposes; and third, plans of constructing such tools.

Applied to steam-engines, the same rule holds good. Steam, as a motive agent, should first be studied, then the operation of steam machinery, and finally the construction of steam-engines. This is a rule that may not apply in all cases, but the exceptions are few.

To follow the same chain of reasoning still farther, and to show what may be gained by method and system in learning mechanics, it may be assumed that machine functions consist in the application of power, and therefore power should be first studied; of this there can be but one opinion. The learner who sets out to master even the elementary principles of mechanics without first having formed a true conception of power as an element, is in a measure wasting his time and squandering his efforts.

Any truth in mechanics, even the action of the "mechanical powers" before alluded to, is received with an air of mystery, unless the nature of power is first understood. Practical demonstration a hundred times repeated does not create a conviction of truth in mechanical propositions, unless the principles of operation are understood.

An apprentice may learn that power is not increased or diminished by being transmitted through a train of wheels which change both speed and force, and he may believe the proposition without having a "conviction" of its truth. He must first learn to regard power as a constant and indestructible element—something that may be weighed, measured, and transmitted, but not created or destroyed by mechanism; then the nature of the mechanism may be understood, but not before.

To obtain a true understanding of the nature of power is by no

means the difficulty for a beginner that is generally supposed; and when once reached, the truth will break upon the mind like a sudden discovery, and ever afterwards be associated with mechanism and motion whenever seen. The learner will afterwards find himself analysing the flow of water, the traffic in the streets, the movement of ships and trains; even the act of walking will become a manifestation of power, all clear and intelligible, without that air of mystery that is otherwise inseparable from the phenomena of motion. If the learner will go on farther, and study the connection between heat and force, the mechanical equivalent of heat when developed into force and motion, and the reconversion of power into heat, he will have commenced at the base of what must constitute a thorough knowledge of mechanics, without which he will have to continually proceed under difficulties.

I am well aware of the popular opinion that such subjects are too abstruse to be understood by practical mechanics—an assumption that is founded mainly in the fact that the subject of heat and motion are not generally studied, and have been too recently demonstrated in a scientific way to command confidence and attention; but the subject is really no more difficult to understand in an elementary sense than that of the relation between movement and force illustrated in the "mechanical powers" of school-books, which no apprentice ever did or ever will understand, except by first studying the principles of force and motion, independent of mechanical agents, such as screws, levers, wedges, and so on.

It is to be regretted that there has not been books especially prepared to instruct mechanical students in the relations between heat, force, motion, and practical mechanism. The subject is, of course, treated at great length in modern scientific works, but is not connected with the operations of machinery in a way to be easily understood by beginners. A treatise on the subject, called "The Correlation and Conservation of Forces," published by D. Appleton & Co. of New York, is perhaps as good a book on the subject as can at this time be referred to. The work contains papers contributed by Professors Carpenter, Grove, Helmotz, Faraday, and others, and has the advantage of arrangement in short sections, that compass the subject without making it tedious.

In respect to books and reading, the apprentice should supply himself with references. A single book, and the best one that can

be obtained on each of the different branches of engineering, is enough to begin with. A pocket-book for reference, such as Molesworth's or Nystrom's, is of use, and should always be at hand. For general reading, nothing compares with the scientific and technical journals, which are now so replete with all kinds of information. Beside noting the present progress of engineering industry in all parts of the world, they contain nearly all besides that a learner will require.

It will be found that information of improvements and mechanical progress that a learner may gather from serial publications can always be exchanged for special knowledge in his intercourse with skilled workmen, who have not the opportunity or means of reading for themselves; and what an apprentice may read and learn in an hour can often be "exchanged" for experimental knowledge that has cost years to acquire.

(1.) Into what two divisions can a knowledge of constructive mechanics be divided?—(2.) Give an example of your own to distinguish between special and general knowledge.—(3.) In what manner is special knowledge mostly acquired?—(4.) What has been the effect of scientific investigations upon special knowledge?—(5.) What is meant by the division of labour?—(6.) Why have engineering tools been less changed than most other kinds of machinery during twenty years past?—(7.) What is meant by machine functions; adaptation; construction?—(8.) Why has the name "mechanical powers" been applied to screws, levers, wedges, and so on?—(9.) Can power be conceived of as an element or principle, independent of mechanism?

CHAPTER II.

MECHANICAL ENGINEERING.

THIS work, as already explained, is to be devoted to mechanical engineering, and in view of the difference of opinion that exists as to what mechanical engineering comprehends, and the different sense in which the term is applied, it will be proper to explain what is meant by it here.

I am not aware that any one has defined what constitutes civil engineering, or mechanical engineering, as distinguished one

from the other, nor is it assumed to fix any standard here farther than to serve the purpose of explaining the sense in which the terms will be used; yet there seems to be a clear line of distinction, which, if it does not agree with popular use of the terms, at least seems to be furnished by the nature of the business itself. It will therefore be assumed that mechanical engineering relates to dynamic forces and works that involve *machine motion*, and comprehends the conditions of machine action, such as torsional, centrifugal, intermittent, and irregular strains in machinery, arising out of motion; the endurance of wearing surfaces, the constructive processes of machine-making and machine effect in the conversion of material—in short, agents for converting, transmitting, and applying power.

Civil engineering, when spoken of, will be assumed as referring to works that do not involve *machine motion*, nor the use of power, but deal with static forces, the strength, nature, and disposition of material under constant strains, or under measured strains, the durability and resistance of material, the construction of bridges, factories, roads, docks, canals, dams, and so on; also levelling and surveying. This corresponds to the most common use of the term civil engineering in America, but differs greatly from its application in Europe, where civil engineering is understood as including machine construction, and where the term engineering is applied to ordinary manufacturing processes.

Civil engineering, in the meaning assumed for the term, has become almost a pure mathematical science. Constants are proved and established for nearly every computation; the strength and durability of materials, from long and repeated tests, has come to be well understood; and as in the case of machine tools, the uniformity of practice among civil engineers, and the perfection of their works, attest how far civil engineering has become a true science, and proves that the principles involved in the construction of permanent works are well understood.

To estimate how much is yet to be learned in mechanical engineering, we have only to apply the same test, and when we contrast the great variance between the designs of machines and the diversity of their operation, even when applied to similar purposes, their imperfection is at once apparent. It must, however, be considered that if the rules of construction were uniform, and the principles of machine operation as well understood as the strength and arrangement of material in permanent struc-

tures, still there would remain the difficulty of adaptation to new processes, which are continually being developed.

If the steam-engine, for instance, had forty years ago been brought to such a state of improvement as to be constructed with standard proportions and arrangement for stationary purposes, all the rules, constants, and data of whatever kind that had been collected and proved, would have been but of little use in adapting steam-engines to railways and the purposes of navigation.

Mechanical engineering has by the force of circumstances been divided up into branches relating to engineering tools, railway machinery, marine engines, and so on; either branch of which constitutes a profession within itself. Most thorough study will be required to master general principles, and then a further effort to acquire proficiency in some special branch, without which there is but little chance of success at the present day.

To master the various details of machine manufacture, including draughting, founding, forging, and fitting, is of itself a work equal to most professional pursuits, to say nothing of manual skill; and when we come to add machine functions and their application, generating and transmitting power, with other things that will necessarily be included in practice, the task assumes proportions that makes it appear a hopeless one. Besides, the work of keeping progress with the mechanic arts calls for a continual accretion of knowledge; and it is no small labour to keep informed of the continual changes and improvements that are going on in all parts of the world, which may at any time modify and change both machines and processes. But few men, even under the most favourable conditions, have been able to qualify themselves as competent mechanical engineers sooner than at forty years of age.

One of the earliest cares of an apprentice should be to divest his mind of what I will call the romance of mechanical engineering, almost inseparable from such views as are often acquired in technological schools. He must remember that it is not a science he is studying, and that mathematics deal only with one branch of what is to be learned. Special knowledge, or what does not come within the scope of general principles, must be gained in a most practical way, at the expense of hard work, bruised fingers, and a disregard of much that the world calls gentility.

Looking ahead into the future, the apprentice can see a field for the mechanical engineer widening on every side. As the construction of permanent works becomes more settled and uniform, the application of power becomes more diversified, and develops problems of greater number. No sooner has some great improvement, like railway and steam navigation, settled into system and regularity than new enterprises begin. To offset the undertaking of so great a work as the study of mechanical engineering, there is the very important advantage of the exclusiveness of the calling—a condition that arises out of its difficulties. If there is a great deal to learn, there is also much to be gained in learning it. It is seldom, indeed, that an efficient mechanical engineer fails to command a place of trust and honour, or to accumulate a competency by means of his calling.

If a civil engineer is wanted to survey railways, construct docks, bridges, buildings, or permanent works of any kind, there are scores of men ready for the place, and qualified to discharge the duties; but if an engineer is wanted to design and construct machinery, such a person is not easy to be found, and if found, there remains that important question of competency; for the work is not like that of constructing permanent works, where several men may and will perform the undertaking very much in the same manner, and perhaps equally well. In the construction of machinery it is different; the success will be directly as the capacity of the engineer, who will have but few precedents, and still fewer principles, to guide him, and generally has to set out by relying mainly upon his special knowledge of the operation and application of such machines as he has to construct.

(1.) How may mechanical be distinguished from civil engineering?—(2.) What test can be applied to determine the progress made in any branch of engineering?—(3.) What are some of the conditions which prevent the use of constants in machine construction?—(4.) Is mechanical engineering likely to become more exact and scientific?—(5.) Name some of the principal branches of mechanical engineering.—(6.) Which is the most extensive and important?

CHAPTER III.

ENGINEERING AS A CALLING.

It may in the abstract be claimed that the dignity of any pursuit is or should be as the amount of good it confers, and the influence it exerts for the improvement of mankind. The social rank of those engaged in the various avocations of life has, in different countries and in different ages, been defined by various standards. Physical strength and courage, hereditary privilege, and other things that once recommended men for preferment, have in most countries passed away or are regarded as matters of but little importance, and the whole civilised world have agreed upon one common standard, that knowledge and its proper use shall be the highest and most honourable attainment to which people may aspire.

It may be useless or even wrong to institute invidious comparisons between different callings which are all useful and necessary, and the matter is not introduced here with any view of exalting the engineering profession; it is for some reasons regretted that the subject is alluded to at all, but there is too much to be gained by an apprentice having a pride and love for his calling to pass over the matter of its dignity as a pursuit without calling attention to it. The gauntlet has been thrown down and comparison provoked by the unfair and unreasonable place that the politician, the metaphysician, and the moral philosopher have in the past assigned to the sciences and constructive arts. Poetry, metaphysics, mythology, war, and superstition have in their time engrossed the literature of the world, and formed the subject of what was alone considered education.

In a half century past all has changed; the application of the sciences, the utilisation of natural forces, manufacturing, the transportation of material, the preparation and diffusion of printed matter, and other great matters of human interest, have come to shape our laws, control commerce, establish new relations between people and countries—in short, has revolutionised the world. So rapid has been this change that it has outrun the powers of conception, and people waken as from a dream to find themselves governed by a new master.

Considering material progress as consisting primarily in the demonstration of scientific truths, and secondly, in their application to useful purposes, we can see the position of the engineer as an agent in this great work of reconstruction now going on around us. The position is a proud one, but not to be attained except at the expense of great effort, and a denial of everything that may interfere with the acquirement of knowledge during apprenticeship and the study which must follow.

The mechanical engineer deals mainly with the natural forces, and their application to the conversion of material and transport. His calling involves arduous duties; he is brought in contact with what is rough and repulsive, as well as what is scientific and refined. He must include grease, dirt, manual labour, undesirable associations, and danger with apprenticeship, or else be content to remain without thoroughly understanding his profession.

(1.) What should determine the social rank of industrial callings?—(2.) Why have the physical sciences and mechanic arts achieved so honourable a position?—(3.) How may the general object of the engineering arts be described?—(4.) What is the difference between science and art as the terms are generally employed in connection with practical industry?

CHAPTER IV.

THE CONDITIONS OF APPRENTICESHIP.

Were it not that moral influences in learning mechanics, as in all other kinds of education, lie at the bottom of the whole matter, the subject of this chapter would not have been introduced. But it is the purpose, so far as possible, to notice everything that concerns an apprentice and learner, and especially what he has to deal with at the outset; hence some remarks upon the nature of apprentice engagements will not be out of place. To acquire information or knowledge of any kind successfully and permanently, it must be a work of free volition, as well as from a sense of duty or expediency; and whatever tends to create love and respect for a pursuit or calling, becomes one of the strongest

incentives for its acquirement, and the interest taken by an apprentice in his business is for this reason greatly influenced by the opinions that he may hold concerning the nature of his engagement.

The subject of apprentice engagements seems in the abstract to be only a commercial one, partaking of the nature of ordinary contracts, and, no doubt, can be so construed so far as being an exchange of "considerations," but no farther. Its intricacy is established by the fact that all countries where skilled labour exists have attempted legislation to regulate apprenticeship, and to define the terms and conditions between master and apprentice; but, aside from preventing the abuse of powers delegated to masters, and in some cases forcing a nominal fulfilment of conditions defined in contracts, such legislation, like that intended to control commerce and trade, or the opinions of men, has failed to attain the objects for which it was intended.

This failure of laws to regulate apprenticeship, which facts fully warrant us in assuming, is due in a large degree to the impossibility of applying general rules to special cases; it may be attributed to the same reasons which make it useless to fix values or the conditions of exchange by legislation. What is required is that the master, the apprentice, and the public should understand the true relations between them—the value of what is given and what is received on both sides. When this is understood, the whole matter will regulate itself without any interference on the part of the law.

The subject is an intricate one, and has been so much affected by the influence of machine improvement, and a corresponding decrease in what may be called special knowledge, that rules and propositions which would fifty years ago apply to the conditions of apprenticeship, will at the present day be wrong and unjust. Viewed in a commercial sense, as an exchange of considerations or values, apprenticeship can be regarded like other engagements; yet, what an apprentice gives as well as what he receives are alike too conditional and indefinite to be estimated by ordinary standards. An apprentice exchanges unskilled or inferior labour for technical knowledge, or for the privilege and means of acquiring such knowledge. The master is presumed to impart a kind of special knowledge, collected by him at great expense and pains, in return for the gain derived from the unskilled labour of the learner. This special knowledge given by the master

may be imparted in a longer or shorter time; it may be thorough and valuable, or not thorough, and almost useless. The privileges of a shop may be such as to offset a large amount of valuable labour on the part of the apprentice, or these privileges may be of such a character as to be of but little value, and teach inferior plans of performing work.

On the other hand, the amount that an apprentice may earn by his labour is governed by his natural capacity, and by the interest he may feel in advancing; also from the view he may take of the equity of his engagement, and the estimate that he places upon the privileges and instruction that he receives. In many branches of business, where the nature of the operations carried on are measurably uniform, and have not for a long time been much affected by changes and improvements, the conditions of apprenticeship are more easy to define; but mechanical engineering is the reverse of this, it lacks uniformity both as to practice and what is produced. To estimate the actual value of apprentice labour in an engineering-work is not only a very difficult matter, but to some extent impracticable even by those of long experience and skilled in such investigations; and it is not to be expected that a beginner will under such circumstances be able to understand the value of such labour: he is generally led to the conclusion that he is unfairly treated, that his services are not sufficiently paid for, and that he is not advanced rapidly enough.

With these conclusions in his mind, but little progress will be made, and hence the reason for introducing the subject here.

The commercial value of professional or technical knowledge is generally as the amount of time, effort, and unpaid labour that has been devoted to its acquirement. This value is sometimes modified by the exclusiveness of some branch that has been made the object of special study. Exclusiveness is, however, becoming exceptional, as the secrets of manufacture and special knowledge are supplanted by the application of general principles; it is a kind of artificial protection thrown around certain branches of industry, and must soon disappear, as unjust to the public and unnecessary to success.

In business arrangements, technical knowledge and professional experience become capital, and offset money or property, not under any general rule, nor even as a consideration of which the law can define the value or prescribe conditions for. The estimate placed upon technical knowledge when rated as capital

in the organisation of business firms, and wherever it becomes necessary to give such knowledge a commercial value, furnishes the best and almost the only source from which an apprentice can form an opinion of the money value of what he is to acquire during his apprenticeship.

An apprentice at first generally forms an exaggerated estimate of what he has to learn; it presents to his mind not only a great undertaking, but a kind of mystery, which he fears that he may not be able to master. The next stage is when he has made some progress, and begins to underrate the task before him, and imagine that the main difficulties are past, that he has already mastered all the leading principles of mechanics, which is, after all, but a "small matter." In a third stage an apprentice experiences a return of his first impressions as to the difficulties of his undertaking; he begins to see his calling as one that must involve endless detail, comprehending things which can only be studied in connection with personal experience; he sees "the horizon widen as it recedes," that he has hardly begun the task, instead of having completed it—even despairs of its final accomplishment.

In the workshop, mechanical knowledge of some kind is continually and often insensibly acquired by a learner, who observes the operations that are going on around him; he is continually availing himself of the experience of those more advanced, and learns by association the rules and customs of the shop, of the business, and of discipline and management. He gathers the technical terms of the fitting-shop, the forge and foundry; notes the operations of planing, turning, drilling, and boring, with the names and application of the machines directed to these operations. He sees the various plans of lifting and moving material, the arrangement and relation of the several departments to facilitate the course of the work in process; he also learns where the product of the works is sold, discusses the merits and adaptation of what is constructed, which leads to considering the wants that create a demand for this product, and the extent and nature of the market in which it is sold.

All these things constitute technical knowledge, and the privilege of their acquirement is an element of value. The common view taken of the matter, however, is that it costs nothing for a master to afford these privileges—the work must at any rate be carried on, and is not retarded by being watched

and learned by apprentices. Viewed from any point, the privileges of engineering establishments have to be considered as an element of value, to be bought at a price, just as a ton of iron or a certain amount of labour is; and in a commercial sense, as an exchangeable equivalent for labour, material, or money. In return a master receives the unskilled labour or service of the learner; this service is presumed to be given at a reduced rate, or sometimes without compensation, for the privileges of the works and the instruction received.

In forming an estimate of the value of his services, an apprentice sees what his hands have performed, compares it with what a skilled man will do, and estimates accordingly, assuming that his earnings are in proportion to what has been done; but this is a mistake, and a very different standard must be assumed to arrive at the true value of such unskilled labour.

Apprentice labour, as distinguished from skilled labour, has to be charged with the extra attention in management, the loss that is always occasioned by a forced classification of the work, the influence in lowering both the quality and the amount of work performed by skilled men, the risk of detention by failure or accident, and loss of material; besides, apprentices must be charged with the same, if not a greater expense than skilled workmen, for light, room, oil, tools, and office service. Attempts have been made in some of the best-regulated engineering establishments to fix some constant estimate upon apprentice labour, but, so far as known, without definite results in any case. If not combined with skilled labour, it would be comparatively easy to determine the value of apprentice labour; but when it comes up as an item in the aggregate of labour charged to a machine or some special work constructed, it is difficult, if not impossible, to separate skilled from unskilled service.

Another condition of apprenticeship that is equally as difficult to define as the commercial value of mechanical knowledge, or that of apprentice labour, is the extent and nature of the facilities that different establishments afford for learners.

In speaking of the mechanical knowledge to be gained, and of the privileges afforded for learners in engineering-works in a general way, it must, of course, be assumed that such works afford full facilities for learning some branch of work by the best practice and in the most thorough manner. Such establishments are, however, graded from the highest class, on the best

branches of work, where a premium would be equitable, down to the lowest class, performing only inferior branches of work, where there can be little if any advantage gained by serving an apprenticeship.

Besides this want or difference of facilities which establishments may afford, there is the farther distinction to be made between an engineering establishment and one that is directed to the manufacture of staple articles. This distinction between engineering-works and manufacturing is quite plain to engineers themselves, but in many cases is not so to those who are to enter as apprentices, nor to their friends who advise them. In every case where engagements are made there should be the fullest possible investigation as to the character of the works, not only to protect the learner, but to guard regular engineering establishments in the advantages to be gained by apprentice labour. A machinist or a manufacturer who employs only the muscular strength and the ordinary faculties of workmen in his operations, can afford to pay an apprentice from the beginning a fair share of his earnings; but an engineering-work that projects original plans, generates designs, and assumes risks based upon skill and special knowledge, is very different from a manufactory. To manufacture is to carry on regular processes for converting material; such processes being constantly the same, or approximately so, and such as do not demand much mechanical knowledge on the part of workmen.

The name of having been an apprentice to a famous firm may sometimes have an influence in enabling an engineer to form advantageous commercial connections, but generally an apprenticeship is of value only as it has furnished substantial knowledge and skill; for every one must sooner or later come down to the solid basis of their actual abilities and acquirements. The engineering interest is by far too practical to recognise a shadow instead of true substance, and there is but little chance of deception in a calling which deals mainly with facts, figures, and positive demonstration.

It is best, when an apprentice thinks of entering an engineering establishment, to inquire of its character from disinterested persons who are qualified to judge of the facilities it affords. As a rule, every machine-shop proprietor imagines his own establishment to combine all the elements of an engineering business—and the fewer the facilities for learners, usually the

more extravagant this estimate; so that opinions in the matter, to be relied upon, should come from disinterested sources.

In regard to premiums, it is a matter to be determined by the facilities that a work may afford for teaching apprentices. To include experience in all the departments of an engineering establishment, within a reasonable term, none but those of unusual ability can make their services of sufficient value to offset what they receive; and there is no doubt but that premium engagements, when the amount of the premium is based upon the facilities afforded for learning, are fair and equitable.

There is, however, this to be remembered, that the considerations which more especially balance premiums—such as a term at draughting, designing, and office service—may be mainly acquired by self-effort, while the practical knowledge of moulding, forging, and fitting cannot; and an apprentice who has good natural capacity, may, if industrious, by the aid of books and such opportunities as usually exist, qualify himself very well without including the premium departments in his course.

Finally, it must constantly be borne in mind that what will be learned is no less a question of faculties than effort, and that the means of succeeding are closed to none who at the beginning form proper plans, and follow them persistently.

(1.) Why cannot the conditions of apprentice engagements be determined by law?—(2.) In what manner does machine improvements affect the conditions of apprenticeship?—(3.) What are the considerations which pass from a master to an apprentice?—(4.) What from an apprentice to a master?—(5.) Why is a particular service of less value when performed by an apprentice than by a skilled workman?—(6.) In what manner can technical knowledge be made to balance or become capital?—(7.) Name two of the principal distinctions between technical knowledge and property as constituting capital.—(8.) What is the difference between what is called engineering and regular manufactures?

CHAPTER V.

THE OBJECT OF MECHANICAL INDUSTRY.

Mechanical engineering, like every other business pursuit, is directed to the accumulation of wealth; and as the attainment of any purpose is more surely achieved by keeping that purpose continually in view, there will be no harm, and perhaps considerable gain derived by an apprentice considering at the beginning the main object to which his efforts will be directed after learning his profession or trade. So far as an abstract principle of motives, the subject is of course unfit to consider in connection with engineering operations, or shop manipulation; but business objects have a practical application to be followed throughout the whole system of industrial pursuits, and are as proper to be considered in connection with machine-manufacturing as mechanical principles, or the functions and operation of machines.

The cost of production is an element that continually modifies or improves manufacturing processes, determines the success of every establishment, and must be considered continually in making drawings, patterns, forgings, and castings. Machines are constructed because of *the difference between what they cost and what they sell for*—between their manufacturing cost and market value when they are completed.

It seems hard to deprive engineering pursuits of the romance that is often attached to the business, and bring it down to a matter of commercial gain; but it is best to deal with facts, especially when such facts have an immediate bearing upon the general object in view. There is no intention in these remarks of disparaging the works of many noble men, who have given their means, their time, and sometimes their lives, to the advancement of the industrial arts, without hope or desire of any other reward than the satisfaction of having performed a duty; but we are dealing with facts, and no false colouring should prevent a learner from forming practical estimates of practical matters.

The following propositions will place this subject of aims and objects before the reader in the sense intended:—

First. The main object of mechanical engineering is commercial gain—the profits derived from planning and constructing machinery.

Second. The amount of gain so derived is as the difference between the cost of constructing machinery, and the market value of the machinery when completed.

Third. The difference between what it costs to plan and construct machinery and what it will sell for, is generally as the amount of engineering knowledge and skill brought to bear in the processes of production.

This last sentence brings the matter into a tangible form, and indicates what the subject of gain should have to do with what an apprentice learns of machine construction. Success in an engineering enterprise may be temporarily achieved by illegitimate means—such as misrepresentation of the capacity and quality of what is produced, the use of cheap or improper material, or by copying the plans of others to avoid the expense of engineering service—but in the end the permanent success of an engineering business must rest upon the knowledge and skill that is connected with it.

By examining into the facts, an apprentice will find that all truly successful establishments have been founded and built upon the mechanical abilities of some person or persons whose skill formed a base upon which the business was reared, and that true skill is the element which must in the end lead to permanent success. The material and the labour which make up the first cost of machines are, taking an average of various classes, nearly equally divided; labour being in excess for the finer class of machinery, and the material in excess for the coarser kinds of work. The material is presumed to be purchased at the same rates by those of inferior skill as by those that are well skilled, so that the difference in the first, or manufacturing cost of machinery, is determined mainly by skill.

Skill, in the sense employed here, consists not only in preparing plans and in various processes for converting and shaping material, but also in the general conduct of an establishment, including estimates, records, system, and so on, which will be noticed in their regular order. The amount of labour involved, and consequently the first cost of machinery, is in a large degree as the number of mechanical processes required, and the time consumed in each operation; to reduce the number of these processes

or operations, shorten the time in which they may be performed, and improve the quality of what is produced, is the business of the mechanical engineer. A careful study of shop operations or processes, including designing, draughting, moulding, forging, and fitting, is the secret of success in engineering practice, or in the management of manufactures. The advantages of an economical design, and the most carefully-prepared drawings, are easily neutralised and lost by careless or improper manipulation in the workshop; an incompetent manager may waste ten pounds in shop processes, while the commercial department of a work saves one pound by careful buying and selling.

This importance of shop processes in machine construction is generally realised by proprietors, but not thoroughly understood in all of its bearings; an apprentice may notice the continual effort that is made to augment the production of engineering-works, which is the same thing as shortening the processes.

A machine may be mechanically correct, arranged with symmetry, true proportions, and proper movements; but if such a machine has not commercial value, and is not applicable to a useful purpose, it is as much a failure as though it were mechanically inoperative. In fact, this consideration of cost and commercial value must be continually present; and a mechanical education that has not furnished a true understanding of the relations between commercial cost and mechanical excellence will fall short of achieving the objects for which such an education is undertaken. By reasoning from such premises as have been laid down, an apprentice may form true standards by which to judge of plans and processes that he is brought in contact with, and the objects for which they are conducted.

(1.) To what general object are all pursuits directed?—(2.) What besides wealth may be objects in the practice of engineering pursuits?—(3.) Name some of the most common among the causes which reduce the cost of production.—(4.) Name five of the main elements which go to make up the cost of engineering products.—(5.) Why is commercial success generally a true test of the skill connected with engineering-works?

CHAPTER VI.

ON THE NATURE AND OBJECTS OF MACHINERY.

MACHINES do not create or consume, but only transmit and apply power; and it is only by conceiving of power as a constant element, independent of every kind of machinery, that the learner can reach a true understanding of the nature of machines. When once there is in the mind a fixed conception of power, dissociated from every kind of mechanism, there is laid, so to speak, a solid foundation on which an understanding of machines may be built up.

To believe a fact is not to learn it, in the sense that these terms may be applied to mechanical knowledge; to believe a proposition is not to have a conviction of its truth; and what is meant by learning mechanical principles is, as remarked in a previous place, to have them so fixed in the mind that they will involuntarily arise to qualify everything met with that involves mechanical movement. For this reason it has been urged that learners should begin by first acquiring a clear and fixed conception of power, and next of the nature and classification of machines, for without the first he cannot reach the second.

Machines may be defined in general terms as agents for converting, transmitting, and applying power, or motion and force, which constitute power. By machinery the natural forces are utilised, and directed to the performance of operations where human strength is insufficient, when natural force is cheaper, and when the rate of movement exceeds what the hands can perform. The term "agent" applied to machines conveys a true idea of their nature and functions.

Machinery can be divided into four classes, each constituting a division that is very clearly defined by functions performed, as follows:—

First. Motive machinery for utilising or converting the natural forces.

Second. Machinery for transmitting and distributing power.

Third. Machinery for applying power.

Fourth. Machinery of transportation.

Or, more briefly stated—

Motive machinery.

Machinery of transmission.
Machinery of application.
Machinery of transportation.

These divisions of machinery will next be treated of separ-
tely, with a view of making the classification more clear, and explain the principles of operation in each division. This ssertation will form a kind of base upon which the prac-
cal part of the treatise will in a measure rest. It is trusted that e reader will carefully consider each proposition that is laid wn, and on his own behalf pursue the subjects farther than e limits here permit.

(1.) To what three general objects are machines directed ?—(2.) How e machines distinguished from other works or structures ?—(3.) Into at four classes can machinery be divided ?—(4.) Name one principal pe in each of these four divisions.

CHAPTER VII.

MOTIVE MACHINERY.

this class belong—

Steam-engines.
Caloric or air engines.
Water-wheels or water-engines.
Wind-wheels or pneumatic engines.

These four types comprehend the motive-power in general use the present day. In considering different engines for motive-wer in a way to best comprehend their nature, the first view be taken is that they are all directed to the same end, and all l with the same power; and in this way avoid, if possible, the pression of there being different kinds of power, as the terms ter-power, steam-power, and so on, seem to imply. We speak steam-power, water-power, or wind-power; but power is the ne from whatever source derived, and these distinctions merely icate different natural sources from which power is derived, the different means employed to utilise and apply it.

Primarily, power is a product of heat; and wherever force d motion exist, they can be traced to heat as the generating

element: whether the medium through which the power is obtained be by the expansion of water or gases, the gravity of water, or the force of wind, heat will always be found as the prime source. So also will the phenomenon of expansion be found a constant principle of developing power, as will again be pointed out. As steam-engines constitute a large share of the machinery commonly met with, and as a class of machinery naturally engrosses attention in proportion, the study of mechanics generally begins with steam-engines, or steam machinery, as it may be called.

The subject of steam-power, aside from its mechanical consideration, is one that may afford many useful lessons, by tracing its history and influence, not only upon mechanical industry, but upon human interests generally. This subject is often treated of, and both its interest and importance conceded; but no one has, so far as I know, from statistical and other sources, ventured to estimate in a methodical way the changes that can be traced directly and indirectly to steam-power.

The steam-engine is the most important, and in England and America best known among motive agents. The importance of steam contrasted with other sources of motive-power is due not so much to a diminished cost of power obtained in this way, but for the reason that the amount of power produced can be determined at will, and in most cases without reference to local conditions; the machinery can with fuel and water be transported from place to place, as in the case of locomotives which not only supply power for their own transit, but move besides vast loads of merchandise, or travel.

For manufacturing processes, one importance of steam-power rests in the fact that such power can be taken to the material; and beside other advantages gained thereby, is the difference in the expense of transporting manufactured products and the raw material. In the case of iron manufacture, for example, it would cost ten times as much to transport the ore and the fuel used in smelting as it does to transport the manufactured iron; steam-power saves this difference, and without such power our present iron traffic would be impossible. In a great many manufacturing processes steam is required for heating, bleaching, boiling, and so on; besides, steam is now to a large extent employed for warming buildings, so that even when water or other power is employed, in most cases steam-generating

apparatus has to be set up in addition. In many cases waste steam or waste heat from a steam-engine can be employed for the purposes named, saving most of the expense that must be incurred if special apparatus is employed.

Other reasons for the extended and general use of steam as a power, besides those already named, are to be found in the fact that no other available element or substance can be expanded to a given degree at so small a cost as water; and that its temperature will not rise to a point injurious to machinery, and, further, in the very important property of lubrication which steam possesses, protecting the frictional surfaces of pistons and valves, which it is impossible to keep oiled because of their inaccessibility or temperature.

The steam-engine, in the sense in which the term is employed, means not only steam-using machinery, but steam-generating machinery or plant; it includes the engine proper, with the boiler, mechanism for feeding water to the boiler, machinery for governing speed, indicators, and other details.

An apprentice must guard against the too common impression that the engine, cylinder, piston, valves, and so on, are the main parts of steam machinery, and that the boiler and furnace are only auxiliaries. The boiler is, in fact, the base of the whole, that part where the power is generated, the engine being merely an agent for transmitting power from the boiler to work that is performed. This proposition would, of course, be reached by any one in reasoning about the matter and following it to a conclusion, but the fact should be fixed in the mind at the beginning.

When we look at a steam-engine there are certain impressions conveyed to the mind, and by these impressions we are governed in a train of reflection that follows. We may conceive of a cylinder and its details as a complete machine with independent functions, or we can conceive of it as a mechanical device for transmitting the force generated by a boiler, and this conception might be independent of, or even contrary to, specific knowledge that we at the same time possessed; hence the importance of starting with a correct idea of the boiler being, as we may say, the base of steam machinery.

As reading books of fiction sometimes expands the mind and enables it to grasp great practical truths, so may a study of abstract principles often enable us to comprehend the simplest

forms of mechanism. Even Humboldt and Agassiz, it is said, resorted sometimes to imaginative speculations as a means of enabling them to grasp new truths.

In no other branch of machinery has so much research and experiment been made during eighty years past as in steam machinery, and, strange to say, the greater part of this research has been directed to the details of engines; yet there has been no improvement made during the time which has effected any considerable saving of heat or expense. The steam-engines of fifty years ago, considered as steam-using machines, utilised nearly the same proportion of the energy or power developed by the boiler as the most improved engines of modern construction —a fact that in itself indicates that an engine is not the vital part of steam machinery. There is not the least doubt that if the efforts to improve steam-engines had been mainly directed to economising heat and increasing the evaporative power of boilers, much more would have been accomplished with the same amount of research. This remark, however, does not apply to the present day, when the principles of steam-power are so well understood, and when heat is recognised as the proper element to deal with in attempts to diminish the expense of power. There is, of course, various degrees of economy in steam-using as well as in steam-generating machinery; but so long as the best steam machinery does not utilise but one-tenth or one-fifteenth part of the heat represented in the fuel burned, there need be no question as to the point where improvements in such machinery should be mainly directed.

The principle upon which steam-engines operate may be briefly explained as follows:—

A cubic inch of water, by taking up a given amount of heat, is expanded to more than five hundred cubic inches of steam, at a pressure of forty-five pounds to the square inch. This extraordinary expansion, if performed in a close vessel, would exert a power five hundred times as great as would be required to force the same quantity of water into the vessel against this expansive pressure; in other words, the volume of the water when put into the vessel would be but one five-hundredth part of its volume when it is allowed to escape, and this expansion, when confined in a steam-boiler, exerts the force that is called steam-power. This force or power is, through the means of the engine and its details, communicated and applied to different kinds of

work where force and movement are required. The water employed to generate steam, like the engine and the boiler, is merely an agent through which the energy of heat is applied.

This, again, reaches the proposition that power is heat, and heat is power, the two being convertible, and, according to modern science, indestructible; so that power, when used, must give off its mechanical equivalent of heat, or heat, when utilised, develop its equivalent in power. If the whole amount of heat represented in the fuel used by a steam-engine could be applied, the effect would be, as before stated, from ten to fifteen times as great as it is in actual practice, from which it must be inferred that a steam-engine is a very imperfect machine for utilising heat. This great loss arises from various causes, among which is that the heat cannot be directly nor fully communicated to the water. To store up and retain the water after it is expanded into steam, a strong vessel, called a boiler, is required, and all the heat that is imparted to the water has to pass through the plates of this boiler, which stand as a wall between the heat and its work.

To summarise, we have the following propositions relating to steam machinery:—

1. The steam-engine is an agent for utilising the power of heat and applying it to useful purposes.

2. The power of a steam-engine is derived by expanding water in a confining vessel, and employing the force exerted by pressure thus obtained.

3. The power developed is as the difference of volume between the feed-water forced into the boiler, and the volume of the steam that is drawn from the boiler, or as the amount of heat taken up by the water.

4. The heat that may be utilised is what will pass through the plates of the boiler, and be taken up by the water, and is but a small share of what the fuel produces.

5. The boiler is the main part, where power is generated, and the engine is but an agent for transmitting this power to the work performed.

6. The loss of power in a steam-engine arises from the heat carried off in the exhaust steam, loss by radiation, and the friction of the moving parts.

7. By condensing the steam before it leaves the engine, so that the steam is returned to the air in the form of water, and

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of the same volume as when it entered the boiler, there is a gain effected by avoiding atmospheric pressure, varying according to the perfection of the arrangements employed.

Engines operated by means of hot air, called caloric engines, and engines operated by gas, or explosive substances, all act substantially upon the same general principles as steam-engines; the greatest distinction being between those engines wherein the generation of heat is by the combustion of fuel, and those wherein heat and expansion are produced by chemical action. With the exception of a limited number of caloric or air engines, steam machinery comprises nearly all expansive engines that are employed at this day for motive-power; and it may be safely assumed that a person who has mastered the general principles of steam-engines will find no trouble in analysing and understanding any machinery acting from expansion due to heat, whether air, gas, or explosive agents be employed.

This method of treating the subject of motive-engines will no doubt be presenting it in a new way, but it is merely beginning at an unusual place. A learner who commences with first principles, instead of pistons, valves, connections, and bearings, will find in the end that he has not only adopted the best course, but the shortest one to understand steam and other expansive engines.

(1.) What is principal among the details of steam machinery?—(2.) What has been the most important improvement recently made in steam machinery?—(3.) What has been the result of expansive engines generally stated?—(4.) Why has water proved the most successful among various expansive substances employed to develop power?—(5.) Why does a condensing engine develop more power than a non-condensing one?—(6.) How far back from its development into power can heat be traced as an element in nature?—(7.) Has the property of combustion a common source in all substances?

CHAPTER VIII.

WATER-POWER.

WATER-WHEELS, next to steam-engines, are the most common motive agents. For centuries water-wheels remained without much improvement or change down to the period of turbine wheels, when it was discovered that instead of being a very simple matter, the science of hydraulics and water-wheels involved some very intricate conditions, giving rise to many problems of scientific interest, that in the end have produced the class known as turbine wheels.

A modern turbine water-wheel, one of the best construction, operating under favourable conditions, gives a percentage of the power of the water which, after deducting the friction of the wheel, almost reaches the theoretical coefficient or equals the gravity of the water; it may therefore be assumed that there will in the future be but little improvement made in such water-wheels except in the way of simplifying and cheapening their construction. There is, in fact, no other class of machines which seem to have reached the same state of improvement as water-wheels, nor any other class of machinery that is constructed with as much uniformity of design and arrangement, in different countries, and by different makers.

Water-wheels, or water-power, as a mechanical subject, is apparently quite disconnected with shop manipulation, but will serve as an example for conveying general ideas of force and motion, and, on these grounds, will warrant a more extended notice than the seeming connection with the general subject calls for.

In the remarks upon steam-engines it was explained that power is derived from heat, and that the water and the engine were both to be regarded as agents through which power was applied, and further, that power is always a product of heat. There is, perhaps, no problem in the whole range of mechanics more interesting than to trace the application of this principle in machinery; one that is not only interesting but instructive, and may suggest to the mind of an apprentice a course of

investigation that will apply to many other matters connected with power and mechanics.

Power derived from water by means of wheels is due to the gravity of the water in descending from a higher to a lower level; but the question arises, What has heat to do with this? If heat is the source of power, and power a product of heat, there must be a connection somewhere between heat and the descent of the water. Water, in descending from one level to another, can give out no more power than was consumed in raising it to the higher level, and this power employed to raise the water is found to be heat. Water is evaporated by heat of the sun, expanded until it is lighter than the atmosphere, rises through the air, and by condensation falls in the form of rain over the earth's surface; then drains into the ocean through streams and rivers, to again resume its round by another course of evaporation, giving out in its descent power that we turn to useful account by means of water-wheels. This principle of evaporation is continually going on; the fall of rain is likewise quite constant, so that streams are maintained within a sufficient regularity to be available for operating machinery.

The analogy between steam-power and water-power is therefore quite complete. Water is in both cases the medium through which power is obtained; evaporation is also the leading principle in both, the main difference being that in the case of steam-power the force employed is directly from the expansion of water by heat, and in water-power the force is an indirect result of expansion of water by heat.

Every one remembers the classification of water-wheels met with in the older school-books on natural philosophy, where we are informed that there are three kinds of wheels, as there were "three kinds of levers"—namely, overshot, undershot, and breast wheels—with a brief notice of Barker's mill, which ran apparently without any sufficient cause for doing so. Without finding fault with the plan of describing water-power commonly adopted in elementary books, farther than to say that some explanation of the principles by which power is derived from the water would have been more useful, I will venture upon a different classification of water-wheels, more in accord with modern practice, but without reference to the special mechanism of the different wheels, except when unavoidable. Water-wheels can be divided into four general types.

First. Gravity wheels, acting directly from the weight of the water which is loaded upon a wheel revolving in a vertical plane, the weight resting upon the descending side until the water has reached the lowest point, where it is discharged.

Second. Impact wheels, driven by the force of spouting water that expends its percussive force or momentum against the vanes tangental to the course of rotation, and at a right angle to the face of the vanes or floats.

Third. Reaction wheels, that are "enclosed," as it is termed, and filled with water, which is allowed to escape under pressure through tangental orifices, the propelling force being derived from the unbalanced pressure within the wheel, or from the reaction due to the weight and force of the water thrown off from the periphery.

Fourth. Pressure wheels, acting in every respect upon the principle of a rotary steam-engine, except in the differences that arise from operating with an elastic and a non-elastic fluid; the pressure of the water resting continually against the vanes and "abutment," without means of escape except by the rotation of the wheel.

To this classification may be added combination wheels, acting partly by the gravity and partly by the percussion force of the water, by impact combined with reaction, or by impact and maintained pressure.

Gravity, or "overshot" wheels, as they are called, for some reasons will seem to be the most effective, and capable of utilising the whole effect due to the gravity of the water; but in practice this is not the case, and it is only under peculiar conditions that wheels of this class are preferable to turbine wheels, and in no case will they give out a greater per cent. of power than turbine wheels of the best class. The reasons for this will be apparent by examining the conditions of their operation.

A gravity wheel must have a diameter equal to the fall of water, or, to use the technical name, the height of the head. The speed at the periphery of the wheel cannot well exceed sixteen feet per second without losing a part of the effect by the wheel anticipating or overrunning the water. This, from the large diameter of the wheels, produces a very slow axial speed, and a train of multiplying gearing becomes necessary in order to reach the speed required in most operations where power is

applied. This train of gearing, besides being liable to wear and accident, and costing usually a large amount as an investment, consumes a considerable part of the power by frictional resistance, especially when such gearing consists of tooth wheels. Gravity wheels, from their large size and their necessarily exposed situation, are subject to be frozen up in cold climates; and as the parts are liable to be first wet and then dry, or warm and cold by exposure to the air and the water alternately, the tendency to corrosion if constructed of iron, or to decay if of wood, is much greater than in submerged wheels. Gravity wheels, to realise the highest measure of effect from the water, require a diameter so great that they must drag in the water at the bottom or delivering side, and are for this reason especially affected by back-water, to which all wheels are more or less liable from the reflux of tides or by freshets. These disadvantages are among the most notable pertaining to gravity wheels, and have, with other reasons—such as the inconvenience of construction, greater cost, and so on—driven such wheels out of use by the force of circumstances, rather than by actual tests or theoretical deductions.

Impact wheels, or those driven by the percussive force of water, including the class termed turbine water-wheels, are at this time generally employed for heads of all heights.

The general theory of their action may be explained in the following propositions:—

1. The spouting force of water is theoretically equal to its gravity.

2. The percussive force of spouting water can be fully utilised if its motion is altogether arrested by the vanes of a wheel.

3. The force of the water is greatest by its striking against planes at right angles to its course.

4. Any force resulting from water rebounding from the vanes parallel to their face, or at any angle not reverse to the motion of the wheel, is lost.

5. This rebounding action becomes less as the columns of water projected upon the wheel are increased in number and diminished in size.

6. To meet the conditions of rotation in the wheel, and to facilitate the escape of the water without dragging, after it has expended its force upon the vanes, the reversed curves of the turbine is the best-known arrangement.

It is, of course, very difficult to deal with so complex a subject as the present one with words alone, and the reader is recommended to examine drawings, or, what is better, water-wheels themselves, keeping the above propositions in view.

Modern turbine wheels have been the subject of the most careful investigation by able engineers, and there is no lack of mathematical data to be referred to and studied after the general principles are understood. The subject, as said, is one of great complicity if followed to detail, and perhaps less useful to a mechanical engineer who does not intend to confine his practice to water-wheels, than other subjects that may be studied with greater advantage. The subject of water-wheels may, indeed, be called an exhausted one that can promise but little return for labour spent upon it—with a view to improvements, at least. The efforts of the ablest hydraulic engineers have not added much to the percentage of useful effect realised by turbine wheels during many years past.

Reaction wheels are employed to a limited extent only, and will soon, no doubt, be extinct as a class of water-wheels. In speaking of reaction wheels, I will select what is called Barker's mill for an example, because of the familiarity with which it is known, although its construction is greatly at variance with modern reaction wheels.

There is a problem as to the principle of action in a Barker wheel, which although it may be very clear in a scientific sense, remains a puzzle to the minds of many who are well versed in mechanics, some contending that the power is directly from pressure, others that it is from the dynamic effect due to reaction. It is one of the problems so difficult to determine by ordinary standards, that it serves as a matter of endless debate between those who hold different views; and considering the advantage usually derived from such controversies, perhaps the best manner of disposing of the problem here is to state the two sides as clearly as possible, and leave the reader to determine for himself which he thinks right.

Presuming the vertical shaft and the horizontal arms of a Barker wheel to be filled with water under a head of sixteen feet, there would be a pressure of about seven pounds upon each superficial inch of surface within the cross arm, exerting an equal force in every direction. By opening an orifice at the sides of these arms equal to one inch of area, the pressure would at that

point be relieved by the escape of the water, and the internal pressure be unbalanced to that extent. In other words, opposite this orifice, and on the other side of the arm, there would be a force of seven pounds, which being unbalanced, acts as a propelling power to drive the wheel.

This is one theory of the principle upon which the Barker wheel operates, which has been laid down in Vogdes' "Mensuration," and perhaps elsewhere. The other theory alluded to is that, direct action and reaction being equal, ponderable matter discharged tangentally from the periphery of a wheel must create a reactive force equal to the direct force with which the weight is thrown off. To state it more plainly, the spouting water that issues from the arm of a Barker wheel must react in the opposite course in proportion to its weight.

The two propositions may be consistent with each other or even identical, but there still remains an apparent difference.

The latter seems a plausible theory, and perhaps a correct one; but there are two facts in connection with the operation of reaction water-wheels which seem to controvert the latter and favour the first theory, namely, that reaction wheels in actual practice seldom utilise more than forty per cent. of useful effect from the water, and that their speed may *exceed the initial velocity of the water.* With this the subject is left as one for argument or investigation on the part of the reader.

Pressure wheels, like gravity wheels, should, from theoretical inference, be expected to give a high per cent. of power. The water resting with the whole of its weight against the vanes or abutments, and without chance of escape except by turning the wheel, seems to meet the conditions of realising the whole effect due to the gravity of the water, and such wheels would no doubt be economical if they had not to contend with certain mechanical difficulties that render them impracticable in most cases.

A pressure wheel, like a steam-engine, must include running contact between water-tight surfaces, and like a rotary steam-engine, this contact is between surfaces which move at different rates of speed in the same joint, so that the wear is unequal, and increases as the speed or the distance from the axis. When it is considered that the most careful workmanship has never produced rotary engines that would surmount these difficulties in working steam, it can hardly be expected they can be overcome in using water, which is not only liable to be filled

with grit and sediment, but lacks the peculiar lubricating properties of steam. A rotary steam-engine is in effect the same as a pressure water-wheel, and the apprentice in studying one will fully understand the principles of the other.

(1.) What analogy may be found between steam and water power?—(2.) What is the derivation of the name turbine?—(3.) To what class of water-wheels is this name applicable?—(4.) How may water-wheels be classified?—(5.) Upon what principle does a reaction water-wheel operate?—(6.) Can ponderable weight and pressure be independently considered in the case?—(7.) Why cannot radial running joints be maintained in machines?—(8.) Describe the mechanism in common use for sustaining the weight of turbine wheels, and the thrust of propeller shafts.

CHAPTER IX.

WIND-POWER.

Wind-power, aside from the objections of uncertainty and irregularity, is the cheapest kind of motive-power. Steam machinery, besides costing a large sum as an investment, is continually deteriorating in value, consumes fuel, and requires continual skilled attention. Water-power also requires a large investment, greater in many cases than steam-power, and in many places the plant is in danger of destruction by freshets. Wind-power is less expensive in every way, but is unreliable for constancy except in certain localities, and these, as it happens, are for the most part distant from other elements of manufacturing industry. The operation of wind-wheels is so simple and so generally understood that no reference to mechanism need be made here. The force of the wind, moving in right lines, is easily applied to producing rotary motion, the difference from water-power being mainly in the comparative weakness of wind currents and the greater area required in the vanes upon which the wind acts. Turbine wind-wheels have been constructed on very much the same plan as turbine water-wheels. In speaking of wind-power, the propositions about heat must not be forgotten. It has been explained how heat is almost directly utilised by the steam-engine,

and how the effect of heat is utilised by water-wheels in a less direct manner, and the same connection will be found between heat and wind-wheels or wind-power. Currents of air are due to changes of temperature, and the connection between the heat that produces such air currents and their application as power is no more intricate than in the case of water-power.

(1.) What is the difference in general between wind and water wheels?—(2.) Can the course of wind, like that of water, be diverted and applied at pleasure?—(3.) On what principle does wind act against the vanes of a wheel?—(4.) How may an analogy between wind-power and heat be traced?

CHAPTER X.

MACHINERY FOR TRANSMITTING AND DISTRIBUTING POWER.

To construe the term "transmission of power" in its full sense, it will, when applied to machinery, include nearly all that has motion; for with the exception of the last movers, or where power passes off and is expended upon work that is performed, all machinery of whatever kind may be called machinery of transmission. Custom has, however, confined the use of the term to such devices as are employed to convey power from one place to another, without including organised machines through which power is directly applied to the performance of work. Power is transmitted by means of shafts, belts, friction wheels, gearing, and in some cases by water or air, as various conditions of the work to be performed may require. Sometimes such machinery is employed as the conditions do not require, because there is, perhaps, nothing of equal importance connected with mechanical engineering of which there exists a greater diversity of opinion, or in which there is a greater diversity of practice, than in devices for transmitting power.

I do not refer to questions of mechanical construction, although the remark might be true if applied in this sense, but to the kind of devices that may be best employed in certain cases.

It is not proposed at this time to treat of the construction of machinery for transmitting power, but to examine into the conditions that should determine which of the several plans of transmitting is best in certain cases—whether belts, gearing, or shafts should be employed, and to note the principles upon which they operate. Existing examples do not furnish data as to the advantages of the different plans for transmitting power, because a given duty may be successfully performed by belts, gearing, or shafts—even by water, air, or steam—and the comparative advantages of different means of transmission is not always an easy matter to determine.

Machinery of transmission being generally a part of the fixed plant of an establishment, experiments cannot be made to institute comparisons, as in the case of machines; besides, there are special or local considerations—such as noise, danger, freezing, and distance—to be taken into account, which prevent any rules of general application. Yet in every case it may be assumed that some particular plan of transmitting power is better than any other, and that plan can best be determined by studying, first, the principles of different kinds of mechanism and its adaptation to the special conditions that exist; and secondly, precedents or examples.

A leading principle in machinery of transmission that more than any other furnishes data for strength and proper proportions is, that the stress upon the machinery, whatever it may be, is inverse as the speed at which it moves. For example, a belt two inches wide, moving one thousand feet a minute, will theoretically perform the same work that one ten inches wide will do, moving at a speed of two hundred feet a minute; or a shaft making two hundred revolutions a minute will transmit four times as much power as a shaft making but fifty revolutions in the same time, the torsional strain being the same in both cases.

This proposition argues the expediency of reducing the proportions of mill gearing and increasing its speed, a change which has gradually been going on for fifty years past; but there are opposing conditions which make a limit in this direction, such as the speed at which bearing surfaces may run, centrifugal strain, jar, and vibration. The object is to fix upon a point between what high speed, light weight, cheapness of cost suggest, and what the conditions of practical use and endurance demand.

(1.) What does the term "machinery of transmission" include, as applied in common use?—(2.) Why cannot direct comparisons be made between shafts, belts, and gearing?—(3.) Define the relation between speed and strain in machinery of transmission.—(4.) What are the principal conditions which limit the speed of shafts?

CHAPTER XI.

SHAFTS FOR TRANSMITTING POWER.

There is no use in entering upon detailed explanations of what a learner has before him. Shafts are seen wherever there is machinery; it is easy to see the extent to which they are employed to transmit power, and the usual manner of arranging them. Various text-books afford data for determining the amount of torsional strain that shafts of a given diameter will bear; explain that their capacity to resist torsional strain is as the cube of the diameter, and that the deflection from transverse strains is so many degrees; with many other matters that are highly useful and proper to know. I will therefore not devote any space to these things here, but notice some of the more obscure conditions that pertain to shafts, such as are demonstrated by practical experience rather than deduced from mathematical data. What is said will apply especially to what is called line-shafting for conveying and distributing power in machine-shops and other manufacturing establishments. The following propositions in reference to shafts will assist in understanding what is to follow:—

1. The strength of shafts is governed by their size and the arrangement of their supports.

2. The capacity of shafts is governed by their strength and the speed at which they run taken together.

3. The strains to which shafts are subjected are the torsional strain of transmission, transverse strain from belts and wheels, and strains from accidents, such as the winding of belts.

4. The speed at which shafts should run is governed by their size, the nature of the machinery to be driven, and the kind of bearings in which they are supported.

5. As the strength of shafts is determined by their size, and

their size fixed by the strains to which they are subjected, strains are first to be considered.

There were three kinds of strain mentioned—torsional, deflective, and accidental. To meet these several strains the same means have to be provided, which is a sufficient size and strength to resist them; hence it is useless to consider each of these different strains separately. If we know which of the three is greatest, and provide for that, the rest, of course, may be disregarded. This, in practice, is found to be accidental strains to which shafts are in ordinary use subjected, and they are usually made, in point of strength, far in excess of any standard that would be fixed by either torsional or transverse strain due to the regular duty performed.

This brings us back to the old proposition, that for structures which do not involve motion, mathematical data will furnish dimensions; but the same rule will not apply in machinery. To follow the proportions for shafts that would be furnished by pure mathematical data would in nearly all cases lead to error. Experience has demonstrated that for ordinary cases, where power is transmitted and applied with tolerable regularity, a shaft three inches in diameter, making one hundred and fifty revolutions a minute, its bearings three to four diameters in length, and placed ten feet apart, will safely transmit fifty horse-power.

By assuming this or any other well-proved example, and estimating larger or smaller shafts by keeping their diameters as the cube root of the power to be transmitted, the distance between bearings as the diameter, and the speed inverse as the diameter, the reader will find his calculations to agree approximately with the modern practice of our best engineers. This is not mentioned to give proportions for shafts, so much as to call attention to accidental strains, such as winding belts, and to call attention to a marked discrepancy between actual practice and such proportions as would be given by what has been called the measured or determinable strains to which shafts are subjected.

As a means for transmitting power, shafts afford the very important advantage that power can be easily taken off at any point throughout their length, by means of pulleys or gearing, also in forming a positive connection between the motive-power and machines, or between the different parts of machines.

The capacity of shafts in resisting torsional strain is as the cube of their diameter, and the amount of torsional deflection in shafts is as their length. The torsional capacity being based upon the diameter, often leads to the construction of what may be termed diminishing shafts, lines in which the diameter of the several sections are diminished as the distance from the driving power increases, and as the duty to be performed becomes less. This plan of arranging line shafting has been and is yet quite common, but certainly was never arrived at by careful observation. Almost every plan of construction has both advantages and disadvantages, and the best means of determining the excess of either, in any case, is to first arrive at all the conditions as near as possible, then form a "trial balance," putting the advantages on one side and the disadvantages on the other, and footing up the sums for comparison. Dealing with this matter of shafts of uniform diameter and shafts of varying diameter in this way, there may be found in favour of the latter plan a little saving of material and a slight reduction of friction as advantages. The saving of material relates only to first cost, because the expense of fitting is greater in constructing shafts when the diameters of the different pieces vary; the friction, considering that the same velocity throughout must be assumed, is scarcely worth estimating.

For disadvantages there is, on the other hand, a want of uniformity in fittings that prevents their interchange from one part of a line shaft to the other—a matter of great importance, as such exchanges are frequently required. A line shaft, when constructed with pieces of varying diameter, is special machinery, adapted to some particular place or duty, and not a standard product that can be regularly manufactured as a staple article by machinists, and thus afforded at a low price. Pulleys, wheels, bearings, and couplings have all to be specially prepared; and in case of a change, or the extension of lines of shafting, cause annoyance, and frequently no little expense, which may all be avoided by having shafts of uniform diameter. The bearings, besides being of varied strength and proportions, are generally in such cases placed at irregular intervals, and the lengths of the different sections of the shaft are sometimes varied to suit their diameter. With line shafts of uniform diameter, everything pertaining to the shaft—such as hangers, couplings, pulleys, and bearings—is interchangeable; the pulleys, wheels, bearings, or hangers can be placed at plea-

sure, or changed from one part of the shaft to another, or from one part of the works to another, as occasion may require. The first cost of a line of shafting of uniform diameter, strong enough for a particular duty, is generally less than that of a shaft consisting of sections varying in size. This may at first seem strange, but a computation of the number of supports required, with the expense of special fitting, will in nearly all cases show a saving.

Attention has been called to this case as one wherein the conditions of operation obviously furnish true data to govern the arrangement of machinery, instead of the determinable strains to which the parts are subjected, and as a good example of the importance of studying mechanical conditions from a practical and experimental point of view. If the general diameter of a shaft is based upon the exact amount of power to be transmitted, or if the diameter of a shaft at various parts is based upon the torsional stress that would be sustained at these points, such a shaft would not only fail to meet the conditions of practical use, but would cost more by attempting such an adaptation. The regular working strain to which shafts are subjected is inversely as the speed at which they run. This becomes a strong reason in favour of arranging shafts to run at a maximum speed, provided there was nothing more than first cost to consider; but there are other and more important conditions to be taken into account, principal among which are the required rate of movement where power is taken off to machines, and the endurance of bearings.

In the case of line shafting for manufactories, if the speed varies so much from that of the first movers on machines as to require one or more intermediate or counter shafts, the expense would be very great; on the contrary, if countershafts can be avoided, there is a great saving of belts, bearings, machinery, and obstruction. The practical limit of speed for line shafts is in a great measure dependent upon the nature of the bearings, a subject that will be treated of in another place.

(1.) What kind of strains are shafts subjected to?—(2.) What determines the strength of shafts in resisting transverse strain?—(3.) Why are shafts often more convenient than belts for transmitting power?—(4.) What is the difference between the strains to which shafts and belts are subjected?—(5.) What is gained by constructing a line shaft of sections diminishing in size from the first mover?—(6.) What is gained by constructing line shafts of uniform diameter?

CHAPTER XII.

BELTS FOR TRANSMITTING POWER.

The traction of belts upon pulleys, like that of locomotive wheels upon railways, being incapable of demonstration except by actual experience, for a long time hindered the introduction of belts as a means of transmitting motion and power except in cases when gearing or shafts could not be employed. Motion is named separately, because with many kinds of machinery that are driven at high speed—such as wood machines—the transmission of rapid movement must be considered as well as power, and in ordinary practice it is only by means of belts that such high speeds may be communicated from one shaft to another.

The first principle to be pointed out in regard to belts, to distinguish them from shafts as a means of transmitting power, is that power is communicated by means of tensile instead of torsional strain, the power during transmission being represented in the difference of tension between the driving and the slack side of belts. In the case of shafts, their length, or the distance to which they may be extended in transmitting power, is limited by torsional resistance; and as belts are not liable to this condition, we may conclude that unless there are other difficulties to be contended with, belts are more suitable than shafts for transmitting power throughout long distances. Belts suffer resistance from the air and from friction in the bearings of supporting pulleys, which are necessary in long horizontal belts; with these exceptions they are capable of moving at a very high rate of speed, and transmitting power without appreciable loss.

Following this proposition into modern engineering examples, we find how practice has gradually conformed to what these properties in belts suggest. Wire and other ropes of small diameter, to avoid air friction, and allowed to droop in low curves to avoid too many supporting pulleys, are now in many cases employed for transmitting power through long distances, as at Schaffhausen, in Germany. This system has been very successfully applied in some cases for distributing power in large manufacturing establishments. Belts, among which are included all

flexible bands, do not afford the same facilities for taking off power at different points as shafts, but have advantages in transmitting power to portable machinery, when power is to be taken off at movable points, as in the case of portable travelling cranes, machines, and so on.

An interesting example in the use of belts for communicating power to movable machinery is furnished by the travelling cranes of Mr Ramsbottom, in the shops of the L. & N. W. Railway, at Crewe, England, where powerful travelling cranes receive both the lifting and traversing power by means of a cotton rope not more than three-fourths of an inch in diameter, which moves at a high velocity, the motion being reduced by means of tangent wheels and gearing to attain the force required in lifting heavy loads. Observing the operation of this machinery, a person not familiar with the relations between force and motion will be astonished at the effect produced by the small rope which communicates power to the machinery.

Considered as means for transmitting power, the contrast as to advantages and disadvantages lies especially between belts and gearing instead of between belts and shafts. It is true in extreme cases, such as that cited at Crewe, or in conveying water-power from inaccessible places, through long distances, the comparison lies between belts and shafts; but in ordinary practice, especially for first movers, the problem as to mechanism for conveying power lies between belts and gear wheels. If experience in the use of belts was thorough, as it is in the case of gearing, and if the quality of belts did not form so important a part in the estimates, there would be but little difficulty in determining where belts should be employed and where gearing would be preferable. Belts are continually taking the place of gearing even in cases where, until quite recently, their use has been considered impracticable; one of the largest rolling mills in Pittsburg, Pennsylvania, except a single pair of spur wheels as the last movers at each train of rolls, is driven by belts throughout.

Leaving out the matter of a positive relative movement between shafts, which belts as a means of transmitting power cannot insure, there are the following conditions that must be considered in determining whether belts or other means should be employed in transmitting power from one machine to another or between the parts of machines.

1. The distance to which power is to be transmitted.

2. The speed at which the transmitting machinery must move.

3. The course or direction of transmission, whether in straight lines or at angles.

4. The cost of construction and durability.

5. The loss of power during transmission.

6. Danger, noise, vibration, and jar.

In every case where there can be a question as to whether gearing shafts or belts will be the best means of transmitting power, the several conditions named will furnish a solution if they are properly investigated and understood. Speed, noise, or angles may become determinative conditions, and are such in a large number of cases; first cost and loss of power are generally secondary conditions. Applying these tests to cases where belts, shafts, or wheels may be employed, a learner will soon find himself in possession of knowledge to guide him in his own schemes, and enable him to judge of the correctness of examples that come under his notice.

It is never enough to know that any piece of work is commonly constructed in some particular manner, or that a proposition is generally accepted as being correct; a reason should be sought for. Nothing is learned, in the true sense, until the reasons for it are understood, and it is by no means sufficient to know from observation alone that belts are best for high speeds, that gearing is the best means of forming angles in transmitting power, or that gearing consumes more power, and that belts produce less jar and noise; the principles which lie at the bottom must be reached before it can be assumed that the matter is fairly understood.

(1.) Why have belts been found better than shafts for transmitting power through long distances?—(2.) What are the conditions which limit the speed of belts?—(3.) Why cannot belts be employed to communicate positive movement?—(4.) Would a common belt transmit motion positively, if there were no slip on the pulleys?—(5.) Name some of the circumstances to be considered in comparing belts with gearing or shafts as a means of transmitting power.

CHAPTER XIII.

GEARING AS A MEANS OF TRANSMITTING POWER.

THE term gearing, which was once applied to wheels, shafts, and the general mechanism of mills and factories, has now in common use become restricted to tooth wheels, and is in this sense employed here. Gearing as a means of transmitting motion is employed when the movement of machines, or the parts of machines, must remain relatively the same, as in the case of the traversing screw of an engine lathe—when a heavy force is transmitted between shafts that are near to each other, or when shafts to be connected are arranged at angles with each other. This rule is of course not constant, except as to cases where positive relative motion has to be maintained. Noise, and the liability to sudden obstruction, may be reasons for not employing tooth wheels in many cases when the distance between and the position of shafts would render such a connection the most durable and cheap. Gearing under ordinary strain, within limited speed, and when other conditions admit of its use, is the cheapest and most durable mechanism for transmitting power; but the amount of gearing employed in machinery, especially in Europe, is no doubt far greater than it will be in future, when belts are better understood.

No subject connected with mechanics has been more thoroughly investigated than that of gearing. Text-books are replete with every kind of information pertaining to wheels, at least so far as the subject can be made a mathematical one; and to judge from the amount of matter, formulæ, and diagrams, relating to the teeth of wheels that an apprentice will meet with, he will no doubt be led to believe that the main object of modern engineering is to generate wheels. It must be admitted that the teeth of wheels and the proportions of wheels is a very important matter to understand, and should be studied with the greatest care; but it is equally important to know how to produce the teeth in metal after their configuration has been defined on paper; to understand the endurance of teeth under abrasive wear when made of wrought or cast iron, brass or steel; how patterns can be constructed from which correct

wheels may be cast, and how the teeth of wheels can be cut by machinery, and so on.

A learner should, in fact, consider the application and operative conditions of gearing as one of the main parts of the subject, and the geometry or even the construction of wheels as subsidiary; in this way attention will be directed to that which is most difficult to learn, and a part for which facilities are frequently wanting. Gearing may be classed into five modifications—spur wheels, bevel wheels, tangent wheels, spiral wheels, and chain wheels; the last I include among gearing because the nature of their operation is analogous to tooth wheels, although at first thought chains seem to correspond more to belts than gearing. The motion imparted by chains meshing over the teeth of wheels is positive, and not frictional as with belts; the speed at which such chains may run, with other conditions, correspond to gearing.

Different kinds of gearing can be seen in almost every engineering establishment, and in view of the amount of scientific information available, it will only be necessary to point out some of the conditions that govern the use and operation of the different kinds of wheels. The durability of gearing, aside from breaking, is dependent upon pressure and the amount of rubbing action that takes place between the teeth when in contact. Spur wheels, or bevel wheels, when the pitch is accurate and the teeth of the proper form, if kept clean and lubricated, wear but little, because the contact between the teeth is that of rolling instead of sliding. In many cases, one wheel of a pair is filled with wooden cogs; in this arrangement there are four objects, to avoid noise, to attain a degree of elasticity in the teeth, to retain lubricants by absorption in the wood, and to secure by wear a better configuration of the teeth than is usually attained in casting, or even in cutting teeth.

Tangent wheels and spiral gearing have only what is termed line contact between the bearing surfaces, and as the action between these surfaces is a sliding one, such wheels are subject to rapid wear, and are incapable of sustaining much pressure, or transmitting a great amount of power, except the surfaces be hard and lubrication constant. In machinery the use of tangent wheels is mainly to secure a rapid change of speed, usually to diminish motion and increase force.

By placing the axes of tangent gearing so that the threads or

teeth of the pinions are parallel to the face of the driven teeth, as in the planing machines of Messrs Wm. Sellers & Co., the conditions of operation are changed, and an interesting problem arises. The progressive or forward movement of the pinion teeth may be equal to the sliding movement between the surfaces; and an equally novel result is, that the sliding action is distributed over the whole breadth of the driven teeth.

In spiral gearing the line of force is at an angle of forty-five degrees with the bearing faces of the teeth, and the sliding movement equal to the speed of the wheels at their periphery; the bearing on the teeth, as before said, is one of line contact only. Such wheels cannot be employed except in cases where an inconsiderable force is to be transmitted. Spiral wheels are employed to connect shafts that cross each other at right angles but in different planes, and when the wheels can be of the same size.

It may be mentioned in regard to rack gearing for communicating movement to the carriages of planing machines or other purposes of a similar nature: the rack can be drawn to the wheel, and a lifting action avoided, by shortening the pitch of the rack, so that it will vary a little from the driving wheel. The rising or entering teeth in this case do not come in contact with those on the rack until they have attained a position normal to the line of the carriage movement.

(1.) Into what classes can gearing be divided?—(2.) What determines the wearing capacity of gearing?—(3.) What is the advantage gained by employing wooden cogs for gear wheels?—(4.) Why are tangent or worm wheels not durable?

CHAPTER XIV.

HYDRAULIC APPARATUS FOR TRANSMITTING POWER.

Although a system but recently developed, the employment of hydraulic machinery for transmitting and applying power has reached an extended application to a variety of purposes, and gives promise of a still more extensive use in future. Con-

sidered as a means of transmitting regularly a constant amount of power, water apparatus is more expensive and inferior in many respects to belts or shafts, and its use must be traced to some special principle involved which adapts hydraulic apparatus to the performance of certain duties. This principle will be found to consist in storing up power in such a manner that it may be used with great force at intervals; and secondly, in the facilities afforded for multiplying force by such simple mechanism as pumps. An engine of ten-horse-power, connected with machinery by hydraulic apparatus, may provide for a force equal to one hundred horse-power for one-tenth part of the time, the power being stored up by accumulators in the interval; or in other words, the motive power acting continuously can be accumulated and applied at intervals as it may be required for raising weights, operating punches, compressive forging, or other work of an intermittent character. Hydraulic machinery employed for such purposes is more simple and inexpensive than gearing and shafts, especially in the application of a great force acting for a considerable distance, and where a cylinder and piston represent a degree of strength which could not be attained with twice the amount of detail, if gearing, screws, levers, or other devices were employed instead.

Motion or power may be varied to almost any degree by the ratio between the pistons of pumps and the pistons which give off the power, the same general arrangement of machinery answering in all cases; whereas, with gearing the quantity of machinery has to be increased as the motive power and the applied power may vary in time and force. This as said recommends hydraulic apparatus where a great force is required at intervals, and it is in such cases that it was first employed, and is yet for the most part used.

In the use of hydraulic apparatus for transmitting and applying power, there is, however, this difficulty to be contended with: water is inelastic, and for the performance of irregular duty, there is a loss of power equal to the difference between the duty that a piston may perform and what it does perform; that is, the amount of water, and consequently the amount of power given off, is as the movement and volume of the water, instead of as the work done. The application of hydraulic machinery to the lifting and handling of weights will be further noticed in another place.

(1.) Under what conditions is hydraulic apparatus a suitable means for transmitting power?—(2.) To what class of operations is hydraulic apparatus mostly applied?—(3.) Why is not water as suitable a medium as air or steam in transmitting power for general purposes?

CHAPTER XV.

PNEUMATIC MACHINERY FOR TRANSMITTING POWER.

PNEUMATIC machinery, aside from results due to the elasticity of air, is analogous in operation to hydraulic machinery.

Water may be considered as a rigid medium for transmitting power, corresponding to shafts and gear wheels; air as a flexible or yielding one, corresponding to belts. There is at this time but a limited use of pneumatic apparatus for transmitting power, but its application is rapidly extending, especially in transporting material by means of air currents, and in conveying power to mining machinery.

The successful application of the pneumatic system at the Mont Cenis Tunnel in Italy, and at the Hoosac Tunnel in America, has demonstrated the value of the system where the air not only served to transmit power to operate the machinery but to ventilate the mines at the same time. Air brakes for railway trains are another example illustrating the advantages of pneumatic transmission; the force being multiplied at the points where it is applied, so that the connecting pipes are reduced to a small size, the velocity of the air making up for a great force that formerly had to be communicated through rods, chains, or shafts. The principal object attained by the use of air to operate railway brakes is, however, to maintain a connection throughout a train by means of flexible pipes that accommodate themselves to the varying distance between the carriages. Presuming that the flow of air in pipes is not materially impeded by friction or angles, and that there will be no difficulty in maintaining lubrication for pistons or other inaccessible parts of machinery when driven by air, there seems to be many reasons in favour of its use as a means of distributing power in manu-

facturing districts. The diminished cost of motive power when it is generated on a large scale, and the expense and danger of maintaining an independent steam power for each separate establishment where power is employed, especially in cities, are strong reasons in favour of generating and distributing power by compressed air, through pipes, as gas and water are now supplied.

Air seems to be the most natural and available medium for transmitting and distributing power upon any general system like water or gas, and there is every probability of such a system existing at some future time. The power given out by the expansion of air is not equal to the power consumed in compressing it, but the loss is but insignificant compared with the advantages that may be gained in other ways. There is no subject more interesting, and perhaps few more important for an engineering student to study at this time, than the transmission of power and the transport of material by pneumatic apparatus.

In considering pneumatic machinery there are the following points to which attention is directed :—

1. The value of pneumatic apparatus in reaching places where steam furnaces cannot be employed.

2. The use that may be made of air after it has been applied as a motive agent.

3. The saving from condensation, to which steam is exposed, avoidance of heat, and the consequent contraction and expansion of long conducting pipes.

4. The loss of power by friction and angles in conducting air through pipes.

5. The lubrication of surfaces working under air pressure, such as the pistons and valves of engines.

6. The diminished cost of generating power on a large scale, compared with a number of separate steam engines distributed over manufacturing districts.

7. The effect of pneumatic machinery in reducing insurance rates and danger of fire.

8. The expense of the appliances of distribution and their maintenance.

In passing thus rapidly over so important a subject, and one that admits of so extended a consideration as machinery of transmission, the reader can see that the purpose has been to touch only upon such points as will lead to thought and investi-

gation, and especially to meet such queries as are most likely to arise in the mind of a learner. In arranging and erecting machinery of transmission, obviously the first problem must be, what kind of machinery should be employed, and what are the conditions which should determine the selection and arrangement? What has been written has, so far as possible, been directed to suggesting proper means of solving these questions.

(1.) In what respect are air and water like belts and gearing, as means to transmit power?—(2.) What are some of the principal advantages gained by employing air to operate railway breaks?—(3.) Name some of the advantages of centralising motive power.—(4.) Are the conditions of working an engine the same whether air or steam is employed?

CHAPTER XVI.

MACHINERY OF APPLICATION.

The term application has been selected as a proper one to distinguish machines that expend and apply power, from those that are employed in generating or transmitting power. Machines of application employed in manufacturing, and which expend their action on material, are directed to certain operations which are usually spoken of as processes, such as cutting, compressing, grinding, separating, and disintegrating.

By classifying these processes, it will be seen that there is in all but a few functions to be performed by machines, and that they all act upon a few general principles. Engineering tools employed in fitting are, for example, all directed to the process of cutting. Planing machines, lathes, drilling machines, and shaping machines are all cutting machines, acting upon the same general plan—that of a cleaving wedge propelled in straight or curved lines.

Cutting, as a process in converting material, includes the force to propel cutting edges, means to guide and control their action, and mechanism to sustain and adjust the material acted upon. In cutting with hand tools, the operator performs the two functions

of propelling and guiding the tools with his hands; but in what is called power operations, machines are made to perform these functions. In nearly all processes machines have supplanted hand labour, and it may be noticed in the history and development of machine tools that much has been lost in too closely imitating hand operations when machines were first applied. To be profitable, machines must either employ more force, guide tools with more accuracy, or move them at greater speed, than is attainable by hand. Increased speed may, although more seldom, be an object in the employment of machinery, as well as the guidance of implements or increased force in propelling them. The hands of workmen are not only limited as to the power that may be exerted, and unable to guide tools with accuracy, but are also limited to a slow rate of movement, so that machines can be employed with great advantage in many operations where neither the force nor guidance of tools are wanting.

There is nothing more interesting, or at the same time more useful, in the study of mechanics, than to analyse the action of cutting machines or other machinery of application, and to ascertain in examples that come under notice whether the main object of a machine is increased force, more accurate guidance, or greater speed than is attainable by hand operations. Cutting machines as explained may be directed to either of these objects singly, or to all of them together, or these objects may vary in their relative importance in different operations; but in all cases where machines are profitably employed, their action can be traced to one or more of the functions named.

To follow this matter further. It will be found in such machines as are directed mainly to augmenting force or increasing the amount of power that may be applied in any operation, such as sawing wood or stone, the effect produced when compared to hand labour is nearly as the difference in the amount of power applied; and the saving that such machines effect is generally in the same proportion. A machine that can expend ten horse-power in performing a certain kind of work, will save ten times as much as a machine directed to the same purpose expending but one horse-power; this of course applies to machines for the performance of the coarser kinds of work, and employed to supplant mere physical effort. In other machines of application, such as are directed mainly to guidance, or speed of action, such as sewing machines, dove-tailing machines, gear-cutting machines,

and so on, there is no relation whatever between the increased effect that may be produced and the amount of power expended.

The difference between hand and machine operations, and the labour-saving effect of machines, will be farther spoken of in another place; the subject is alluded to here, only to enable the reader to more fully distinguish between machinery of transmission and machinery of application. Machinery of application, directed to what has been termed compression processes, such as steam hammers, drops, presses, rolling mills, and so on, act upon material that is naturally soft and ductile, or when it is softened by heat, as in the case of forging.

In compression processes no material is cut away as in cutting or grinding, the mass being forced into shape by dies or forms that give the required configuration. The action of compressing machines may be either intermittent, as in the case of rolling mills; percussive, as in steam hammers, where a great force acts throughout a limited distance; or gradual and sustained, as in press forging. Machines of application, for abrading or grinding, are constantly coming more into use; their main purpose being to cut or shape material too hard to be acted upon by compression or by cutting processes. It follows that the necessity for machines of this kind is in proportion to the amount of hard material which enters into manufactures; in metal work the employment of hardened steel and iron is rapidly increasing, and as a result, grinding machines have now a place among the standard machine tools of a fitting shop.

Grinding, no doubt, if traced to the principles that lie at the bottom, is nothing more than a cutting process, in which the edges employed are harder than any material that can be made into cutters, the edges firmly supported by being imbedded into a mass as the particles of sand are in grindstones, or the particles of emery in emery wheels.

Separating machines, such as bolts and screens, which may be called a class, require no explanation. The employment of magnetic machines to separated iron and brass filings or shop waste, may be noted as a recent improvement of some importance.

Disintegrating machines, such as are employed for pulverising various substances, grinding grain or pulp, separating fibrous material, and so on, are, with some exceptions, simple enough to be readily understood. One of these exceptions is the rotary "disintegrators," recently introduced, about the action of which

some diversity of opinion exists. The effect produced is certainly abrasive wear, the result of the pieces or particles striking one against another, or against the revolving beaters and casing. The novelty of the process is in the augmented effect produced by a high velocity, or, in other words, the rapidity of the blows.

(1.) Name five machines as types of those employed in the general processes of converting material.—(2.) Name some machines, the object of which is to augment force—One to attain speed—One directed to the guidance of tools.—(3.) What is the difference between the hot and cold treatment of iron as to processes—As to dimensions?—(4.)

CHAPTER XVII.

MACHINERY FOR MOVING AND HANDLING MATERIAL.

STEAM and other machinery applied to the transport of material and travel, in navigation and by railways, comprises the greater share of what may be called engineering products; and when we consider that this vast interest of steam transport is less than a century old, and estimate its present and possible future influence on human affairs, we may realise the relation that mechanical science bears to modern civilisation.

To follow out the application of power to the propulsion of vessels and trains, with the many abstruse problems that would of necessity be involved, would be to carry this work far beyond the limits within which it is most likely to be useful to the apprentice engineer; besides, it would be going beyond what can properly be termed manipulation.

Marine and railway engineering have engrossed the best talent in the world; investigation and research has been expended upon these subjects in a degree commensurate with their importance, and it would be hard to suggest a single want in the many able text-books that have been prepared upon the subjects. Marine and railway engineering are sciences that may, in a sense, be separated from the ordinary constructive arts, and studied at

the end of a course in mechanical engineering, but are hardly proper subjects for an apprentice to take up at the beginning.

In treating of machinery for transport, as a class, the subject, as far as noticed here, will be confined to moving and handling material as one of the processes of manufacturing, and especially in connection with machine construction. If the amount of time, expense, labour, and machinery devoted to handling material in machine shops is estimated, it becomes a matter of astonishment to as many as have not previously investigated the subject; as an item of expense the handling, often exceeds the fitting on large pieces, and in the heavier class of work demands the most careful attention to secure economical manipulation.

It will be well for an apprentice to begin at once, as soon as he commences a shop course, to note the manner of handling material, watching the operation of cranes, hoists, trucks, tackle, rollers; in short, everything that has to do with moving and handling. The machinery and appliances in ordinary use are simple enough in a mechanical sense, but the principles of handling material are by no means as plain or easy to understand. The diversity of practice seen in various plans of handling and lifting weights fully attests the last proposition, and it is questionable whether there is any other branch of mechanical engineering that is treated less in a scientific way than machinery of this class. I do not allude to the mechanism of cranes and other devices, which are usually well proportioned and generally well arranged, but to the adaptation of such machinery with reference to special or local conditions. There are certain inherent difficulties that have to be encountered in the construction and operation of machinery, for lifting and handling, that are peculiar to it as a class; among these difficulties is the transmission of power to movable mechanism, the intermittent and irregular application of power, severe strains, also the liability to accidents and breakage from such machinery being controlled by the judgment of attendants.

Ordinary machinery, on the reverse, is stationary, generally consumes a regular amount of power, is not subjected to such uncertain strains, and as a rule acts without its operation being controlled by the will of attendants.

The functions required in machinery for handling material in a machine shop correspond very nearly to those of the human hands. Nature in this, as in all other things, where a comparison

is possible, has exceeded man in adaptation; in fact, we cannot conceive of anything more perfect than the human hands for handling material—a duty that forms a great share of all that we term labour.

Considered mechanically as a means of handling material, the human hands are capable of exerting force in any direction, vertically, horizontally, or at any angle, moving at various rates of speed, as the conditions may require, and with varying force within the limits of human strength. These functions enable us to pick up or lay down a weight slowly and carefully, to transport it at a rapid rate to save time, to move it in any direction, and without the least waste of power, except in the case of carrying small loads, when the whole body has to be moved, as in ascending or descending stairs. The power travelling cranes, that are usually employed in machine-fitting establishments, are perhaps the nearest approach that has been made to the human frame in the way of handling mechanism; they, however, lack that very important feature of a movement, the speed of which is graduated at will. It is evident that in machinery of any kind for handling and lifting that moves at a uniform rate of speed, and this rate of speed adapted, as it must be, to the conditions of starting or depositing a load, much time must be lost in the transit, especially when the load is moved for a considerable distance. This uniform speed is perhaps the greatest defect in the lifting machinery in common use, at least in such as is driven by power.

In handling a weight with the hands it is carefully raised, and laid down with care, but moved as rapidly as possible throughout the intervening distance; this lesson of nature has not been disregarded. We find that the attention of engineers has been directed to this principle of variable speed to be controlled at will. The hydraulic cranes of Sir William Armstrong, for example, employ this principle in the most effective manner, not only securing rapid transit of loads when lifted, but depositing or adjusting them with a care and precision unknown to mechanism positively geared or even operated by friction breaks.

The principles of all mechanism for handling loads should be such as to place the power, the rate of movement, and the direction of the force, within the control of an operator, which, as has been pointed out, is the same thing in effect as the action of the human hands.

The safety, simplicity, and reliable action of hydraulic machinery has already led to its extensive employment for moving and lifting weights, and it is fair to assume that the importance and success of this invention fully entitle it to be classed as one of the most important that has been made in mechanical engineering during fifty years past. The application of hydraulic force in operating the machinery used in the processes for steel Bessemer manufacture, is one of the best examples to illustrate the advantages and principles of the hydraulic system. Published drawings and descriptions of Bessemer steel plant explain this hydraulic machinery.

There is, however, a principle in hydraulic machinery that must be taken into account, in comparing it with positively geared mechanism, which often leads to loss of power that in many cases will overbalance any gain derived from the peculiar action of hydraulic apparatus. I allude to the loss of power incident to dealing with an inelastic medium, where the amount of force expended is constant, regardless of the resistance offered. A hydraulic crane, for instance, consumes power in proportion to its movements, and not as the amount of duty performed; it takes the same quantity of water to fill the cylinders of such cranes, whether the water exert much or little force in moving the pistons. The difference between employing elastic mediums like air and steam, and an inelastic medium like water, for transmitting force in performing irregular duty, has been already alluded to, and forms a very interesting study for a student in mechanics, leading, as it does, to the solution of many problems concerning the use and effect of power.

The steam cranes of Mr Morrison, which resemble hydraulic cranes, except that steam instead of water is employed as a medium for transmitting force, combine all the advantages of hydraulic apparatus, except positive movement, and evade the loss of power that occurs in the use of water. The elasticity of the steam is found in practice to offer no obstacle to steady and accurate movement of a load, provided the mechanism is well constructed, while the loss of heat by radiation is but trifling.

To return to shop processes in manufacturing. Material operated upon has to be often, sometimes continually, moved from one place to another to receive successive operations, and this movement may be either vertically or horizontally as determined, first, by the relative facility with which the material

may be raised vertically, or moved horizontally, and secondly, by the value of the ground and the amount of room that may be available, and thirdly by local conditions of arrangement. In large cities, where a great share of manufacturing is carried on, the value of ground is so great that its cost becomes a valid reason for constructing high buildings of several storeys, and moving material vertically by hoists, thus gaining surface by floors, instead of spreading the work over the ground; nor is there any disadvantage in high buildings for most kind of manufacture, including machine fitting even, a proposition that will hardly be accepted in Europe, where fitting operations, except for small pieces, are rarely performed on upper floors.

Vertical handling, although it consumes more power, as a rule costs less, is more convenient, and requires less room than horizontal handling, which is sure to interfere more or less with the constructive operations of a workshop. In machine fitting there is generally a wrong estimate placed upon the value of ground floors, which are no doubt indispensable for the heaviest class of work, and for the heaviest tools; but with an ordinary class of work, where the pieces do not exceed two tons in weight, upper floors if strong are quite as convenient, if there is proper machinery for handling material; in fact, the records of any establishment, where cost accounts are carefully made up, will show that the expense of fitting on upper floors is less than on ground floors. This is to be accounted for by better light, and a removal of the fitting from the influences and interference of other operations that must necessarily be carried on upon ground floors.

For loading and unloading carts and waggons, the convenience of the old outside sling is well known; it is also a well-attested fact that accidents rarely happen with sling hoists, although they appear to be less safe than running platforms or lifts. As a general rule, the most dangerous machinery for handling or raising material is that which pretends to dispense with the care and vigilance of attendants, and the safest machinery that which enforces such attention. The condition which leads to danger in hoisting machinery is, that the power employed is opposed to the force of gravity, and as the force of gravity is acting continually, it is always ready to take advantage of the least cessation in the opposing force employed, and thus drag away the weight for which the two forces are contending;

as a weight when under the influence of gravity is moved at an accelerated velocity, if gravity becomes the master, the result is generally a serious accident. Lifting may be considered a case wherein the contrivances of man are brought to bear in overcoming or opposing a natural force; the imperfect force of the machinery is liable to accident or interruption, but gravity never fails to act. Acting on every piece of matter in proportion to its weight must be some force opposing and equal to that of gravity; for example, a piece of iron lying on a bench is opposed by the bench and held in resistance to gravity, and to move this piece of iron we have to substitute some opposing force, like that of the hands or lifting mechanism, to overcome gravity.

As molecular adhesion keeps the particles of matter together so as to form solids, so the force of gravity keeps objects in their place; and to attain a proper conception of forces, especially in handling and moving material, it is necessary to familiarise the mind with this thought.

The force of gravity acts only in one direction—vertically, so that the main force of hoisting and handling machinery which opposes gravity must also act vertically, while the horizontal movement of objects may be accomplished by simply overcoming the friction between them and the surfaces on which they move. This is seen in practice. A force of a hundred pounds may move a loaded truck, which it would require tons to lift; hence the horizontal movements of material may be easily accomplished by hand with the aid of trucks and rollers, so long as it is moved on level planes; but if a weight has to be raised even a single inch by reason of irregularity in floors, the difference between overcoming frictional contact and opposing gravity is at once apparent.

One of the problems connected with the handling of material is to determine where hand-power should stop and motive-power begin—what conditions will justify the erection of cranes, hoists, or tramways, and what conditions will not. Frequent mistakes are made in the application of power when it is not required, especially for handling material; the too common tendency of the present day being to apply power to every purpose where it is possible, without estimating the actual saving that may be effected. A common impression is that motive power, wherever applied to supplant hand labour in

handling material, produces a gain; but in many cases the fallacy of this will be apparent, when all the conditions are taken into account.

Considered upon grounds of commercial expediency as a question of cost alone, it is generally cheaper to move material by hand when it can be easily lifted or moved by workmen, when the movement is mainly in a horizontal direction, and when the labour can be constantly employed; or, to assume a general rule which in practice amounts to much the same thing, vertical lifting should be done by motive power, and horizontal movement for short distances performed by hand. There is nothing more unnatural than for men to carry loads up stairs or ladders; the effort expended in such cases is one-half or more devoted to raising the weight of the body, which is not utilised in the descent, and it is always better to employ winding or other mechanism for raising weights, even when it is to be operated by manual labour. Speaking of this matter of carrying loads upward, I am reminded of the fact that builders in England and America, especially in the latter country, often have material carried up ladders, while in some of the older European countries, where there is but little pretension to scientific manipulation, bricks are usually tossed from one man to another standing on ladders at a distance of ten to fifteen feet apart.

To conclude. The reader will understand that the difficulties and diversity of practice, in any branch of engineering, create similar or equal difficulties in explaining or reasoning about the operations; and the most that can be done in the limited space allotted here to the subject of moving material, is to point out some of the principles that should govern the construction and adaptation of handling machinery, from which the reader can take up the subject upon his own account, and follow it through the various examples that may come under notice.

To sum up—We have the following propositions in regard to moving and handling material:

1. The most economical and effectual mechanism for handling is that which places the amount of force and rate of movement continually under the control of an operator.

2. The necessity for, and consequent saving effected by, power-machinery for handling is mainly in vertical lifting, horizontal movement being easily performed by hand.

3. The vertical movement of material, although it consumes more power, is more economical than horizontal handling, because less floor room and ground surface is required.

4. The value of handling machinery, or the saving it effects, is as the constancy with which it operates; such machinery may shorten the time of handling without cheapening the expense.

5. Hydraulic machinery comes nearest to filling the required conditions in handling material, and should be employed in cases where the work is tolerably uniform, and the amount of handling will justify the outlay required.

6. Handling material in machine construction is one of the principal expenses to be dealt with; each time a piece is moved its cost is enhanced, and usually in a much greater degree than is supposed.

(1.) Why has the lifting of weights been made a standard for the measure of power?—(2.) Name some of the difficulties to contend with in the operation of machinery for lifting or handling material.—(3.) What analogy exists between manual handling and the operation of hydraulic cranes?—(4.) Explain how the employment of overhead cranes saves room in a fitting shop.—(5.) Under what circumstances is it expedient to move material vertically?—(6.) To what circumstances is the danger of handling mainly attributable?

CHAPTER XVIII.

MACHINE COMBINATION.

The combination of several functions in one machine, although it may not seem an important matter to be considered here, is nevertheless one that has much to do with the manufacture of machines, and constitutes what may be termed a principle of construction.

The reasons that favour combination of functions in machines, and the effects that such combinations may produce, are so various that the problem has led to a great diversity of opinions and practice among both those who construct and even those who employ machines. It may be said, too, that a great share

of the combinations found in machines, such as those to turn, mill, bore, slot, and drill in iron fitting, are not due to any deliberate plan on the part of the makers, so much as to an opinion that such machines represent a double or increased capacity. So far has combination in machines been carried, that in one case that came under the writer's notice, a machine was arranged to perform nearly every operation required in finishing the parts of machinery; completely organised, and displaying a high order of mechanical ability in design and arrangement, but practically of no more value than a single machine tool, because but one operation at a time could be performed

To direct the attention of learners to certain rules that will guide them in forming opinions in this matter of machine combination, I will present the following propositions, and afterwards consider them more in detail:—

First. By combining two or more operations in one machine, the only objects gained are a slight saving in first cost, one frame answering for two or more machines, and a saving of floor room.

Second. In a machine where two or more operations are combined, the capacity of such a machine is only as a single one of these operations, unless more than one can be carried on at the same time without interfering one with another.

Third. Combination machines can only be employed with success when one attendant performs all the operations, and when the change from one to another requires but little adjustment and re-arrangement.

Fourth. The arrangement of the parts of a combination machine have to be modified by the relations between them, instead of being adapted directly to the work to be performed.

Fifth. The cost of special adaptation, and the usual inconvenience of fitting combination machines when their parts operate independently, often equals and sometimes exceeds what is saved in framing and floor space.

Referring first to the saving effected by combining several operations in one machine, there is perhaps not one constructor in twenty that ever stops to consider what is really gained, and perhaps not one purchaser in a hundred that does the same thing. The impression is, that when one machine performs two operations it saves a second machine. A remarkable example of this exists in the manufacture of combination machines in

Europe for working wood, where it is common to find complicated machines that will perform all the operations of a joiner's shop, but as a rule only one thing at a time, and usually in an inconvenient manner, each operation being hampered and interfered with by another; and in changing from one kind of work to another the adjustments and changes generally equal and sometimes exceed the work to be done. What is stranger still is, that such machines are purchased, when their cost often equals that of separate machines to perform the same work.

In metal working, owing to a more perfect division of labour, and a more intelligent manipulation than in wood-working, there is less combination in machines—in fact, a combination machine for metal work is rarely seen at this day, and never under circumstances where it occasions actual loss. The advantage of combination, as said, can only be in the framing and floor space occupied by the machines, but these considerations, to be estimated by a proper standard, are quite insignificant when compared with other items in the cost of machine operating, such as the attendance, interest on the invested cost of the machine, depreciation of value by wear, repairing, and so on.

Assuming, for example, that a machine will cost as much as the wages of an attendant for one year, which is not far from an average estimate for iron working machine tools, and that interest, wear, and repairs amount to ten per cent. on this sum, then the attendance would cost ten times as much as the machine; in other words, the wages paid to a workman to attend a machine is, on an average, ten times as much as the other expenses attending its operation, power excepted. This assumed, it follows that in machine tools any improvement directed to labour saving is worth *ten times* as much as an equal improvement directed to the economy of first cost.

This mode of reasoning will lead to proper estimates of the difference in value between good tools and inferior tools; the results of performance instead of the investment being first considered, because the expenses of operating are, as before assumed, usually ten times as great as the interest on the value of a machine.

In view of these propositions, I need hardly say to what object machine improvements should be directed, nor which of the considerations named are most affected by a combination of machine functions; the fact is, that if estimates could be prepared, show-

... the actual effect of machine combinations, it would astonish those who have not investigated the matter, and in many cases show a loss of the whole cost of such machines each year. The effect of combination machines is, however, by no means uniform; the remarks made apply to standard machines employed in the regular work of an engineering or other establishment. In exceptional cases it may be expedient to use combined machines, as the tool-room of machine-shops, for instance, where one man can readily perform the main part of the work, and where there is but little room for machines. The conditions are especially favourable to combination machines, such as may be used in drilling, turning, milling and so on; but whenever there is a necessity or an opportunity to carry on two or more of these operations at the same time, the cost of separate machines is but a small consideration when compared with the saving of labour that may be effected by independent tools to perform each operation. The tendency of manufacturing processes of every kind, at this time, is to a division of labour, and to a separation of each operation into as many branches as possible, so that study spent in 'segregating' instead of 'aggregating' machine functions is most likely to produce profitable results.

This article has been introduced, not only to give a true understanding of the effect and value of machine combination, but to caution against a common error of confounding machine combination with invention.

A great share of the alleged improvements in machinery, when investigated, will be found to consist in nothing more than the combination of several functions in one machine, the novelty of such arrangement leading to an impression of utility and increased effect.

(1.) What is gained by arranging a machine to perform several different operations?—(2.) What may be lost by such combination?—(3.) What is the main expense attending the operation of machine tools?—(4.) What kind of improvement in machine tools produces the most profitable result?—(5.) What are the principal causes which have led to machine combinations.

CHAPTER XIX.

THE ARRANGEMENT OF ENGINEERING ESTABLISHMENTS.

THE first and, perhaps, the most important matter of all in founding engineering works is that of arrangement. As a commercial consideration affecting the cost of manipulation, and the expense of handling material, the arrangement of an establishment may determine, in a large degree, the profits that may be earned, and, as explained in a previous place, upon this matter of profits depends the success of such works.

Aside from the cost or difficulty of obtaining ground sufficient to carry out plans for engineering establishments, the diversity of their arrangement met with, even in those of modern construction, is no doubt owing to a want of reasoning from general premises. There is always a strong tendency to accommodate local conditions, and not unfrequently the details of shop manipulation are quite overlooked, or are not understood by those who arrange buildings.

The similarity of the operations carried on in all works directed to the manufacture of machinery, and the kind of knowledge that is required in planning and conducting such works, would lead us to suppose that at least as much system would exist in machine shops as in other manufacturing establishments, which is certainly not the case. There is, however, this difference to be considered: that whereas many kinds of establishments can be arranged at the beginning for a specific amount of business, machine shops generally grow up around a nucleus, and are gradually extended as their reputation and the demands for their productions increase; besides, the variety of operations required in an engineering establishment, and change from one class of work to another, are apt to lead to a confusion in arrangement, which is too often promoted, or at least not prevented, by insufficient estimates of the cost of handling and moving material.

Materials consumed in an engineering establishment consist mainly of iron, fuel, sand, and lumber. These articles, or their products, during the processes of manipulation, are continually

approaching the erecting shop, from which finished machinery is sent out after its completion. This constitutes the erecting shop, as a kind of focal centre of a works, which should be the base of a general plan of arrangement. This established, and the foundry, smithy, finishing, and pattern shops regarded as feeding departments to the erecting shop, it follows that the connections between the erecting shop and other departments should be as short as possible, and such as to allow free passage for material and ready communication between managers and workmen in the different rooms. These conditions would suggest a central room for erecting, with the various departments for casting, forging, and finishing, radiating from the erecting shop like the spokes of a wheel, or, what is nearly the same, branching off at right angles on either side and at one end of a hollow square, leaving the fourth side of the erecting room to front on a street or road, permitting free exit for machinery when completed.

The material when in its crude state not only consists of various things, such as iron, sand, coal, and lumber, that must be kept separate, but the bulk of such materials is much greater than their finished product. It is therefore quite natural to receive such material on the outside or "periphery" of the works where there is the most room for entrances and for the separate storing of such supplies. Such an arrangement is of course only possible where there can be access to a considerable part of the boundary of a works, yet there are but few cases where a shop cannot be arranged in general upon the plan suggested. By receiving material on the outside, and delivering the finished product from the centre, communications between the departments of an establishment are the shortest that it is possible to have; by observing the plans of the best establishments of modern arrangement, especially those in Europe, it may be seen that this system is approximated in many of them, especially in establishments devoted to the manufacture of some special class of work.

Handling and moving material is the principal matter to be considered in the arrangement of engineering works. The constructive manipulation can be watched, estimated, and faults detected by comparison, but handling, like the designs for machinery, is a more obscure matter, and may be greatly at fault without its defects being apparent to any but those who

are highly skilled, and have had their attention especially directed to the matter.

Presuming an engineering establishment to consist of one-storey buildings, and the main operations to be conducted on the ground level, the only vertical lifting to be performed will be in the erecting room, where the parts of machines are assembled. This room should be reached in every part by over-head travelling cranes, that cannot only be used in turning, moving, and placing the work, but in loading it upon cars or waggons. One result of the employment of over-head travelling cranes, often overlooked, is a saving of floor-room; in ordinary fitting, from one-third more to twice the number of workmen will find room in an erecting shop if a travelling-crane is employed, the difference being that, in moving pieces they may pass over the top of other pieces instead of requiring long open passages on the floor. So marked is this saving of room effected by over-head cranes, that in England, where they are generally employed, handling is not only less expensive and quicker, but the area of erecting floors is usually one-half as much as in America, where travelling-cranes are not employed.

Castings, forgings, and general supplies for erecting can be easily brought to the erecting shop from the other departments on trucks without the aid of motive power; so that the erecting and foundry cranes will do the entire lifting duty required in any but very large establishments.

The auxiliary departments, if disposed about an erecting shop in the centre, should be so arranged that material which has to pass through two or more departments can do so in the order of the processes, and without having to cross the erecting shop. Casting, boring, planing, drilling, and fitting, for example, should follow each other, and the different departments be arranged accordingly; whenever a casting is moved twice over the same course, it shows fault of arrangement and useless expense. The same rule applies to all kinds of material.

A great share of the handling about an engineering establishment is avoided, if material can be stored and received on a higher level than the working floors; if, for instance, coal, iron, and sand is received from railway cars at an elevation sufficient to allow it to be deposited where it is stored by gravity, it is equivalent to saving the power and expense required to raise the material to such a height, or move it and pile it up, which amounts to the

same thing in the end. It is not proposed to follow the details of shop arrangement, further than to furnish a clue to some of the general principles that should be regarded in devising plans of arrangement. Such principles are much more to be relied upon than even experience in suggesting the arrangement of shops, because all experience must be gained in connection with special local conditions, which often warp and prejudice the judgment, and lead to error in forming plans under circumstances different from those where the experience was gained.

(1.) How may the arrangement of an establishment affect its earnings?—(2.) Why is the arrangement of engineering establishments generally irregular?—(3.) Why should an erecting shop be a base of arrangement in engineering establishments?—(4.) What are the principal materials consumed in engineering works?—(5.) Why is not special experience a safe guide in forming plans of shop arrangement?

CHAPTER XX.

GENERALISATION OF SHOP PROCESSES.

HAVING thus far treated of such general principles and facts connected with practical mechanics as might properly precede, and be of use in, the study of actual manipulation in a workshop, we come next to casting, forging, and finishing, with other details that involve manual as well as mental skill, and to which the term "processes" will apply.

As these shop processes or operations are more or less connected, and run one into the other, it will be necessary at the beginning to give a short summary of them, stating the general object of each, that may serve to render the detailed remarks more intelligible to the reader as he comes to them in their consecutive order.

Designing, or generating the plans of machinery, may be considered the leading element in engineering manufactures or

machine construction, that one to which all others are subordinate, both in order and importance, and is that branch to which engineering knowledge is especially directed. Designing should consist, first, in assuming certain results, and, secondly, in conceiving of mechanical agents to produce these results. It comprehends the geometry of movements, the disposition and arrangement of material, the endurance of wearing surfaces, adjustments, symmetry; in short, all the conditions of machine operation and machine construction. This subject will be again treated of at more length in another section.

Draughting, or drawing, as it is more commonly called, is a means by which mental conceptions are conveyed from one person to another; it is the language of mechanics, and takes the place of words, which are insufficient to convey mechanical ideas in an intelligible manner.

Drawings represent and explain the machinery to which they relate as the symbols in algebra represent quantities, and in a degree admit of the same modifications and experiments to which the machinery itself could be subjected if it were already constructed. Drawings are also an important aid in developing designs or conceptions. It is impossible to conceive of, and retain in the mind, all the parts of a complicated machine, and their relation to each other, without some aid to fix the various ideas as they arise, and keep them in sight for comparison; like compiling statistics, the footings must be kept at hand for reference, and to determine the relation that one thing may bear to another.

In the workshop, the objects of drawing are to communicate plans and dimensions to the workmen, and to enable a division of the labour, so that the several parts of a machine may be operated upon by different workmen at the same time—also to enable classification and estimates of cost to be made, and records kept.

Drawings are, in fact, the base of shop system, upon which depends not only the accuracy and uniformity of what is produced, but also, in a great degree, its cost. Complete drawings of whatever is made are now considered indispensable in the best regulated establishments; yet we are not so far removed from a time when most work was made without drawings, but what we may contrast the present system with

that which existed but a few years ago, when to construct a new machine was a great undertaking, involving generally many experiments and mistakes.

Pattern-making relates to the construction of duplicate models for the moulded parts of machinery, and involves a knowledge of shrinkage and cooling strains, the manner of moulding and proper position of pieces, when cast, to ensure soundness in particular parts. As a branch of machine manufacture, pattern-making requires a large amount of special knowledge, and a high degree of skill; for in no other department is there so much that must be left to the discretion and judgment of workmen.

Pattern-makers have to thoroughly understand drawings, in order to reproduce them on the trestle boards with allowance for shrinkage, and to determine the cores; they must also understand moulding, casting, fitting, and finishing. Pattern-making as a branch of machine manufacture, should rank next to designing and drafting.

Founding and casting relate to forming parts of machinery by pouring melted metal into moulds, the force of gravity alone being sufficient to press or shape it into even complicated forms. As a process for shaping such metal as is not injured by the high degree of heat required in melting, moulding is the cheapest and most expeditious of all means, even for forms of regular outline, while the importance of moulding in producing irregular forms is such that without this process the whole system of machine construction would have to be changed. Founding operations are divided into two classes, known technically as green sand moulding, and loam or dry sand moulding; the first, when patterns or duplicates are used to form the moulds, and the second, when the moulds are built by hand without the aid of complete patterns. Founding involves a knowledge of mixing and melting metals such as are used in machine construction, the preparing and setting of cores for the internal displacement of the metal, cooling and shrinking strains, chills, and many other things that are more or less special, and can only be learned and understood from actual observation and practice.

Forging relates to shaping metal by compression or blows when it is in a heated and softened condition; as a process, it is an intermediate one between casting and what may be called

the cold processes. Forging also relates to welding or joining pieces together by sudden heating that melts the surface only, and then by forcing the pieces together while in this softened or semi-fused state. Forging includes, in ordinary practice, the preparation of cutting tools, and tempering them to various degrees of hardness as the nature of the work for which they are intended may require; also the construction of furnaces for heating the material, and mechanical devices for handling it when hot, with the various operations for shaping, which, as in the case of casting, can only be fully understood by experience and observation.

Finishing and fitting relates to giving true and accurate dimensions to the parts of machinery that come in contact with each other and are joined together or move upon each other, and consists in cutting away the surplus material which has to be left in founding and forging because of the heated and expanded condition in which the material is treated in these last processes. In finishing, material is operated upon at its normal temperature, in which condition it can be handled, gauged, or measured, and will retain its shape after it is fitted. Finishing comprehends all operations of cutting and abrading, such as turning, boring, planing and grinding, also the handling of material; it is considered the leading department in shop manipulation, because it is the one where the work constructed is organised and brought together. The fitting shop is also that department to which drawings especially apply, and other preparatory operations are usually made subservient to the fitting processes.

Shop system may also be classed as a branch of engineering work; it relates to the classification of machines and their parts by symbols and numbers, to records of weight, the expense of cast, forged, and finished parts, and apportions the cost of finished machinery among the different departments. Shop system also includes the maintenance of standard dimensions, the classification and cost of labour, with other matters that partake both of a mechanical and a commercial nature.

In order to render what is said of shop processes more easily understood, it will be necessary to change the order in which they have been named. Designing, and many matters connected with the operation of machines, will be more easily learned and understood after having gone through with what may be called the constructive operations, such as involve manual skill.

(1.) Name the different departments of an engineering establishment. —(2.) What does the engineering establishment include?—(3.) What does the commercial department include?—(4.) The foundry department?—(5.) The forging department?—(6.) The fitting department?—(7.) What does the term shop system mean as generally employed?

CHAPTER XXI.

MECHANICAL DRAWING.

MACHINE-DRAWING may in some respects be said to bear the same relation to mechanics that writing does to literature; persons may copy manuscript, or write from dictation, of what they do not understand; or a mechanical draughtsman may make drawings of a machine he does not understand; but neither such writing or drawing can have any value beyond that of ordinary labour. It is both necessary and expected that a draughtsman shall understand all the various processes of machine construction, and be familiar with the best examples that are furnished by modern practice.

Geometrical drawing is not an artistic art so much as it is a constructive mechanical one; displaying the parts of machinery on paper, is much the same in practice, and just the same in principle, as measuring and laying out work in the shop.

Artistic drawing is addressed to the senses, geometrical drawing is addressed to the understanding. Geometrical drawing may, however, include artistic skill not in the way of ornamentation, but to convey an impression of neatness and completeness, that has by common custom been assumed among engineers, and which conveys to the mind an idea of competent construction in the drawing itself, as well as of the machinery which is represented. Artistic effect, so far as admissible in mechanical drawing, is easy to learn, and should be understood, yet through a desire to make pictures, a beginner is often led to neglect that which is more important in the way of accuracy and arrangement.

It is easy to learn "how" to draw, but it is far from easy to learn

"what" to draw. Let this be kept in mind, not in the way of disparaging effort in learning "how" to draw, for this must come first, but in order that the objects and true nature of the work will be understood.

The engineering apprentice, as a rule, has a desire to make drawings as soon as he begins his studies or his work, and there is not the least objection to his doing so; in fact, there is a great deal gained by illustrating movements and the details of machinery at the same time of studying the principles. Drawings if made should always be finished, carefully inked in, and memoranda made on the margin of the sheets, with the date and the conditions under which the drawings were made. The sheets should be of uniform size, not too large for a portfolio, and carefully preserved, no matter how imperfect they may be. An apprentice who will preserve his first drawings in this manner will some day find himself in possession of a souvenir that no consideration would cause him to part with.

For implements procure two drawing-boards, forty-two inches long and thirty inches wide, to receive double elephant paper; have the boards plain without cleets, or ingenious devices for fastening the paper; they should be made from thoroughly seasoned lumber, at least one and one-fourth inches thick; if thinner they will not be heavy enough to resist the thrust of the T squares.

It is better to have two boards, so that one may be used for sketching and drawing details, which, if done on the same sheet with elevations, dirties the paper, and is apt to lower the standard of the finished drawing by what may be called bad association.

Details and sketches, when made on a separate sheet, should be to a larger scale than elevations. By changing from one scale to another the mind is schooled in proportion, and the conception of sizes and dimensions is more apt to follow the finished work to which the drawings relate.

In working to regular scales, such as one-half, one-eighth, or one-sixteenth size, a good plan is to use a common rule, instead of a graduated scale. There is nothing more convenient for a mechanical draughtsman than to be able to readily resolve dimensions into various scales, and the use of a common rule for fractional scales trains the mind, so that computations come naturally, and after a time almost without effort. A plain T

square, with a parallel blade fastened on the side of the head, but not imbedded into it, is the best; in this way set squares can pass over the head of a T square in working at the edges of the drawing. It is strange that a draughting square should ever have been made in any other manner than this, and still more strange, that people will use squares that do not allow the set squares to pass over the heads and come near to the edge of the board.

A bevel square is often convenient, but should be an independent one; a T square that has a movable blade is not suitable for general use. Combinations in draughting instruments, no matter what their character, should be avoided; such combinations, like those in machinery, are generally mistakes, and their effect the reverse of what is intended.

For set squares, or triangles, as they are sometimes called, no material is so good as ebonite; such squares are hard, smooth, impervious to moisture, and contrast with the paper in colour; besides they wear longer than those made of wood. For instruments, it is best to avoid everything of an elaborate or fancy kind; such sets are for amateurs, not engineers. It is best to procure only such instruments at first as are really required, of the best quality, and then to add others as necessity may demand; in this way, experience will often suggest modifications of size or arrangement that will add to the convenience of a set.

One pair each of three and one-half inch and five inch compasses, two ruling pens, two pairs of spring dividers, one for pens and one for pencils, a triangular boxwood scale, a common rule, and a hard pencil, are the essential instruments for machine-drawing. At the beginning, when "scratching out" will probably form an item in the work, it is best to use Whatman's paper, or the best roll paper, which, of the best manufacture, is quite as good as any other for drawings that are not water-shaded.

In mounting sheets that are likely to be removed and replaced, for the purpose of modification, as working drawings generally are, they can be fastened very well by small copper tacks driven along the edges at intervals of two inches or less. The paper can be very slightly dampened before fastening in this manner, and if the operation is carefully performed the paper will be quite as smooth and convenient to work upon as though it were pasted down; the tacks can be driven down so as to be flush with, or

below the surface of, the paper, and will offer no obstruction to squares.

If a drawing is to be elaborate, or to remain long upon a board, the paper should be pasted down. To do this, first prepare thick mucilage, or what is better, glue, and have it ready at hand, with some slips of absorbent paper an inch or so wide. Dampen the sheet on both sides with a sponge, and then apply the mucilage along the edge, for a width of one-fourth or three-eighths of an inch. It is a matter of some difficulty to place a sheet upon a board; but if the board is set on its edge, the paper can be applied without assistance. Then, by placing the strips of paper along the edge, and rubbing over them with some smooth hard instrument, the edges of the sheet can be pasted firmly to the board, the paper slips taking up a part of the moisture from the edges, which are longest in drying. If left in this condition, the centre will dry first, and the paper be pulled loose at the edges by contraction before the paste has time to dry. It is therefore necessary to pass over the centre of the sheet with a wet sponge at intervals to keep the paper slightly damp until the edges adhere firmly, when it can be left to dry, and will be tight and smooth. In this operation much will be learned by practice, and a beginner should not be discouraged by a few failures. One of the most common difficulties in mounting sheets is in not having the gum or glue thick enough; when thin, it will be absorbed by the wood or the paper, or is too long in drying; it should be as thick as it can be applied with a brush, and made from clean Arabic gum, tragacanth, or fine glue.

Thumb-tacks are of but little use in mechanical drawing except for the most temporary purposes, and may very well be dispensed with altogether; they injure the draughting-boards, obstruct the squares, and disfigure the sheets.

Pencilling is the first and the most important operation in draughting; more skill is required to produce neat pencil-work than to ink in the lines after the pencilling is done.

A beginner, unless he exercises great care in the pencil-work of a drawing, will have the disappointment to find the paper soon becoming dirty from plumbago, and the pencil-lines crossing each other everywhere, so as to give the whole a slovenly appearance. He will also, unless he understands the nature of the operations in which he is engaged, make the mistake of

regarding the pencil-work as an unimportant part, instead of constituting, as it does, the main drawing, and thereby neglect that accuracy which alone can make either a good-looking or a valuable one.

Pencil-work is indeed the main operation, the inking being merely to give distinctness and permanency to the lines. The main thing in pencilling is accuracy of dimensions and stopping the lines where they should terminate without crossing others. The best pencils only are suitable for draughting; if the plumbago is not of the best quality, the points require to be continually sharpened, and the pencil is worn away at a rate that more than makes up the difference in cost between the finer and cheaper grades of pencils, to say nothing of the effect upon a drawing.

It is common to use a flat point for draughting pencils, but a round one will often be found quite as good if the pencils are fine, and some convenience is gained by a round point for free-hand use in making rounds and fillets. A Faber pencil, that has detachable points which can be set out as they are worn away, is convenient for draughting.

For compasses, the lead points should be cylindrical, and fit into a metal sheath without paper packing or other contrivance to hold them; and if a draughtsman has instruments not arranged in this manner, he should have them changed at once, both for convenience and economy.

Ink used in drawing should always be the best that can be procured; without good ink a draughtsman is continually annoyed by an imperfect working of pens, and the washing of the lines if there is shading to be done. The quality of ink can only be determined by experiment; the perfume that it contains, or tin-foil wrappers and Chinese labels, are no indication of quality; not even the price, unless it be with some first-class house. To prepare ink, I can recommend no better plan of learning than to ask some one who understands the matter. It is better to waste a little time in preparing it slowly than to be at a continual trouble with pens, which will occur if the ink is ground too rapidly or on a rough surface. To test ink, a few lines can be drawn on the margin of a sheet, noting the shade, how the ink flows from the pen, and whether the lines are sharp; after the lines have dried, cross them with a wet brush; if they wash readily, the ink is too soft; if they resist the water for a time, and then wash tardily, the ink is good. It cannot be expected that inks

soluble in water can permanently resist its action after drying; in fact, it is not desirable that drawing inks should do so, for in shading, outlines should be blended into the tints where the latter are deep, and this can only be effected by washing.

Pens will generally fill by capillary attraction; if not, they should be made wet by being dipped into water; they should not be put into the mouth to wet them, as there is danger of poison from some kinds of ink, and the habit is not a neat one.

In using ruling pens, they should be held nearly vertical, leaning just enough to prevent them from catching on the paper. Beginners have a tendency to hold pens at a low angle, and drag them on their side, but this will not produce clean sharp lines, nor allow the lines to be made near enough to the edges of square blades or set squares.

In regard to the use of the T square and set squares, no useful rules can be given except to observe others, and experiment until convenient customs are attained. A beginner should be careful of adopting unusual plans, and above all things, of making important discoveries as to new plans of using instruments, assuming that common practice is all wrong, and that it is left for him to develop the true and proper way of drawing. This is a kind of discovery which is very apt to intrude itself at the beginning of an apprentice's course in many matters besides drawing, and often leads him to do and say many things which he will afterwards wish to recall.

It is generally a safe rule to assume that any custom long and uniformly followed by intelligent people is right; and, in the absence of that experimental knowledge which alone enables one to judge, it is safe to receive such customs, at least for a time, as being correct.

Without any wish to discourage the ambition of an apprentice to invent, which always inspires him to laudable exertion, it is nevertheless best to caution him against innovations. The estimate formed of our abilities is very apt to be inversely as our experience, and old engineers are not nearly so confident in their deductions and plans as beginners are.

A drawing being inked in, the next things are tints, dimension, and centre lines. The centre lines should be in red ink, and pass through all points of the drawing that have an axial centre, or where the work is similar and balanced on each side of the line. This rule is a little obscure, but will be best understood

if studied in connection with a drawing, and perhaps as well remembered without further explanation.

Dimension lines should be in blue, but may be in red. Where to put them is a great point in draughting. To know where dimensions are required involves a knowledge of fitting and pattern-making, and cannot well be explained; it must be learned in practice. The lines should be fine and clear, leaving a space in their centre for figures when there is room. The distribution of centre lines and dimensions over a drawing must be carefully studied, for the double purpose of giving it a good appearance and to avoid confusion. Figures should be made like printed numerals; they are much better understood by the workman, look more artistic, and when once learned require but little if any more time than written figures. If the scale employed is feet and inches, dimensions to three feet should be in inches, and above this in feet and inches; this corresponds to shop custom, and is more comprehensive to the workman, however wrong it may be according to other standards.

In sketches and drawings made for practice, such as are not intended for the shop, it is suggested that metrical scales be employed; it will not interfere with feet and inches, and will prepare the mind for the introduction of this system of lineal measurement, which may in time be adopted in England and America, as it has been in many other countries.

In shading drawings, be careful not to use too deep tints, and to put the shades in the right place. Many will contend, and not without good reasons, that working drawings require no shading; yet it will do no harm to learn how and where they can be shaded: it is better to omit the shading from choice than from necessity. Sections must, of course, be shaded—not with lines, although I fear to attack so old a custom, yet it is certainly a tedious and useless one: sections with light ink shading of different colours, to indicate the kind of material, are easier to make, and look much better. By the judicious arrangement of a drawing, a large share of it may be in sections, which in almost every case are the best views to work by. The proper colouring of sections gives a good appearance to a drawing, and conveys an idea of an organised machine, or, to use the shop term, "stands out from the paper." In shading sections, leave a margin of white between the tints and the lines on the upper and left-hand sides of the section: this breaks the connection or

sameness, and the effect is striking; it separates the parts, and adds greatly to the clearness and general appearance of a drawing.

Cylindrical parts in the plane of sections, such as shafts and bolts, should be drawn full, and have a 'round shade,' which relieves the flat appearance—a point to be avoided as much as possible in sectional views.

Conventional custom has assigned blue as a tint for wrought iron, neutral or pale pink for cast iron, and purple for steel. Wood is generally distinguished by "graining," which is easily done, and looks well.

The title of a drawing is a feature that has much to do with its appearance, and the impression conveyed to the mind of an observer. While it can add nothing to the real value of a drawing, it is so easy to make plain letters, that the apprentice is urged to learn this as soon as he begins to draw; not to make fancy letters, nor indeed any kind except plain block letters, which can be rapidly laid out and finished, and consequently employed to a greater extent. By drawing six parallel lines, making five spaces, and then crossing them with equidistant lines, the points and angles in block letters are determined; after a little practice, it becomes the work of but a few minutes to put down a title or other matter on a drawing so that it can be seen and read at a glance in searching for sheets or details.

In the manufacture of machines, there are usually so many sizes and modifications, that drawings should assist and determine in a large degree the completeness of classification and record. Taking the manufacture of machine tools, for example: we cannot well say, each time they are to be spoken of, a thirty-six inch lathe without screw and gearing, a thirty-two inch lathe with screw and gearing, a forty-inch lathe triple geared or double geared, with a twenty or thirty foot frame, and so on. To avoid this it is necessary to assume symbols for machines of different classes, consisting generally of the letters of the alphabet, qualified by a single number as an exponent to designate capacity or different modifications. Assuming, in the case of engine lathes, A to be the symbol for lathes of all sizes, then those of different capacity and modification can be represented in the drawings and records as A^1, A^2, A^3, A^4, and so on, requiring but two characters to indicate a lathe of any kind. These symbols should be marked in large plain letters on the left-hand lower corner of sheets, so that the

manager, workman, or any one else, can see at a glance what the drawings relate to. This symbol should run through the time-book, cost account, sales record, and be the technical name for machines to which it applies; in this way machines will always be spoken of in the works by the name of their symbol.

In making up the time charged to different machines during their construction, a good plan is to supply each workman with a slate and pencil, on which he can enter his time as so many hours or fractions of hours charged to the respective symbols. Instead of interfering with his time, this will increase a workman's interest in what he is doing, and naturally lead to a desire to diminish the time charged to the various symbols. This system leads to emulation among workmen where any operation is repeated by different persons, and creates an interest in classification which workmen will willingly assist in.

When the dimensions and symbols are added to a drawing, the next thing is pattern or catalogue numbers. These should be marked in prominent, plain figures on each piece of casting, either in red or other colour that will contrast with the general face of the drawing. These numbers, to avoid the use of symbols in connection with them, must include consecutively all patterns employed in the business, and can extend to thousands without inconvenience.

A book containing the pattern record should be kept, in which these catalogue numbers are set down, with a short description to identify the different parts to which the numbers belong, so that all the various details of any machine can at any time be referred to. Besides this description, there should be opposite the catalogue of pattern numbers, ruled spaces, in which to enter the weight of castings, the cost of the pattern, and also the amount of turned, planed, or bored surface on each piece when it is finished, or the time required in fitting, which is the same thing. In this book the assembled parts of each machine should be set down in a separate list, so that orders for castings can be made from the list without other references. This system is the best one known to the writer, and is in substance a plan now adopted in many of the best engineering establishments. A complete system in all things pertaining to drawings and classifications should be rigidly adhered to; any plan is better than none, and the schooling of the mind to be had in the observance of systematic rules is a matter not to be neglected. New plans for promoting

system may at any time arise, but such plans cannot be at any time understood and adopted except by those who have cultivated a taste for order and regularity.

In regard to shaded elevations, it may be said that photography has superseded them for the purpose of illustrating completed machines, and but few establishments care to incur the expense of ink-shaded elevations. Shaded elevations cannot be made with various degrees of care, and in a longer or shorter time; there is but one standard for them, and that is that such drawings should be made with great care and skill. Imperfect shaded elevations, although they may surprise and please the unskilled, are execrable in the eyes of a draughtsman or an engineer; and as the making of shaded elevations can be of but little assistance to an apprentice draughtsman, it is better to save the time that must be spent in order to make such drawings, and apply the same study and time to other matters of greater importance.

It is not assumed that shaded elevations should not be made, nor that ink shading should not be learned, but it is thought best to point out the greater importance of other kinds of drawing, too often neglected to gratify a taste for picture-making, which has but little to do with practical mechanics.

Isometrical perspective is often useful in drawing, especially in wood structures, when the material is of rectangular section, and disposed at right angles, as in machine frames. One isometrical view, which can be made nearly as quickly as a true elevation, will show all the parts, and may be figured for dimensions the same as plane views. True perspective, although rarely necessary in mechanical drawing, may be studied with advantage in connection with geometry; it will often lead to the explanation of problems in isometric drawing, and will also assist in free-hand lines that have sometimes to be made to show parts of machinery oblique to the regular planes. Thus far the remarks on draughting have been confined to manipulation mainly. As a branch of engineering work, draughting must depend mainly on special knowledge, and is not capable of being learned or practised upon general principles or rules. It is therefore impossible to give a learner much aid by searching after principles to guide him; the few propositions that follow comprehend nearly all that may be explained in words.

1. Geometrical drawings consist in plans, elevations, and sections; plans being views on the top of the object in a horizon-

tal plane; elevations, views on the sides of the object in vertical planes; and sections, views taken on bisecting planes, at any angle through an object.

2. Drawings in true elevation or in section are based upon flat planes, and give dimensions parallel to the planes in which the views are taken.

3. Two elevations taken at right angles to each other, fix all points, and give all dimensions of parts that have their axis parallel to the planes on which the views are taken; but when a machine is complex, or when several parts lie in the same plane, three and sometimes four views are required to display all the parts in a comprehensive manner.

4. Mechanical drawings should be made with reference to all the processes that are required in the construction of the work, and the drawings should be responsible, not only for dimensions, but for unnecessary expense in fitting, forging, pattern-making, moulding, and so on.

5. Every part laid down has something to govern it that may be termed a "base"—some condition of function or position which, if understood, will suggest size, shape, and relation to other parts. By searching after a base for each and every part and detail, the draughtsman proceeds upon a regular system, continually maintaining a test of what is done. Every wheel, shaft, screw or piece of framing should be made with a clear view of the functions it has to fill, and there are, as before said, always reasons why such parts should be of a certain size, have such a speed of movement, or a certain amount of bearing surface, and so on. These reasons or conditions may be classed as *expedient*, *important*, or *essential*, and must be estimated accordingly. As claimed at the beginning, the designs of machines can only in a limited degree be determined by mathematical data. Leaving out all considerations of machine operation with which books have scarcely attempted to deal, we have only to refer to the element of strains to verify the general truth of the proposition.

Examining machines made by the best designers, it will be found that their dimensions bear but little if any reference to calculated strains, especially in machines involving rapid motion. Accidents destroy constants, and a draughtsman or designer who does not combine special and experimental knowledge with what

he may learn from general sources, will find his services to be of but little value in actual practice.

I now come to note a matter in connection with draughting to which the attention of learners is earnestly called, and which, if neglected, all else will be useless. I allude to indigestion, and its resultant evils. All sedentary pursuits more or less give rise to this trouble, but none of them so much as draughting. Every condition to promote this derangement exists. When the muscles are at rest, circulation is slow, the mind is intensely occupied, robbing the stomach of its blood and vitality, and, worse than all, the mechanical action of the stomach is usually arrested by leaning over the edge of a board. It is regretted that no good rule can be given to avoid this danger. One who understands the evil may in a degree avert it by applying some of the logic which has been recommended in the study of mechanics. If anything tends to induce indigestion, its opposite tends the other way, and may arrest it; if stooping over a board interferes with the action of the digestive organs, leaning back does the opposite; it is therefore best to have a desk as high as possible, stand when at work, and cultivate a constant habit of straightening up and throwing the shoulders back, and if possible, take brief intervals of vigorous exercise. Like rating the horse-power of a steam-engine, by multiplying the force into the velocity, the capacity of a man can be estimated by multiplying his mental acquirements into his vitality.

Physical strength, bone and muscle, must be elements in successful engineering experience; and if these things are not acquired at the same time with a mechanical education, it will be found, when ready to enter upon a course of practice, that an important element, the "propelling power," has been omitted.

(1.) What is the difference between geometric and artistic drawing? —(2.) What is the most important operation in making a good drawing?—(3.) Into what three classes can working drawings be divided?—(4.) Explain the difference between elevations and plans.—(5.) To what extent in general practice is the proportion of parts and their arrangement in machines determined mathematically?

CHAPTER XXII.

PATTERN-MAKING AND CASTING.

PATTERNS and castings are so intimately connected that it would be difficult to treat of them separately without continually confounding them together; it is therefore proposed to speak of pattern-making and moulding under one head.

Every operation in a pattern-shop has reference to some operation in the foundry, and patterns considered separately from moulding operations would be incomprehensible to any but the skilled. Next to designing and draughting, pattern-making is the most intellectual of what may be termed engineering processes—the department that must include an exercise of the greatest amount of personal judgment on the part of the workman, and at the same time demands a high grade of hand skill.

For other kinds of work there are drawings furnished, and the plans are dictated by the engineering department of machinery-building establishments, but pattern-makers make their own plans for constructing their work, and have even to reproduce the drawings of the fitting-shop to work from. Nearly everything pertaining to patterns is left to be decided by the pattern-maker, who, from the same drawings, and through the exercise of his judgment alone, may make patterns that are durable and expensive, or temporary and cheap, as the probable extent of their use may determine.

The expense of patterns should be divided among and charged to the machines for which the patterns are employed, but there can be no constant rules for assessing or dividing this cost. A pattern may be employed but once, or it may be used for years; it is continually liable to be superseded by changes and improvements that cannot be predicted beforehand; and in preparing patterns, the question continually arises of how much ought to be expended on them—a matter that should be determined between the engineer and the pattern-maker, but is generally left to the pattern-maker alone, for the reason that but few mechanical engineers understand pattern-making so well as to dictate plans of construction.

To point out some of the leading points or conditions to be taken into account in pattern-making, and which must be understood in order to manage this department, I will refer to them in consecutive order.

First.—Durability, plans of construction and cost, which all amount to the same thing. To determine this point, there is to be considered the amount of use that the patterns are likely to serve, whether they are for standard or special machines, and the quality of the castings so far as affected by the patterns. A first-class pattern, framed to withstand moisture and rapping, may cost twice as much as another that has the same outline, yet the cheaper pattern may answer almost as well to form a few moulds as an expensive one.

Second.—The manner of moulding and its expense, so far as determined by the patterns, which may be parted so as to be 'rammed up' on fallow boards or a level floor, or the patterns may be solid, and have to be bedded, as it is termed; pieces on the top may be made loose, or fastened on so as to 'cope off;' patterns may be well finished so as to draw clean, or rough so that a mould may require a great deal of time to dress up after a pattern is removed.

Third.—The soundness of such parts as are to be planed, bored, and turned in finishing; this is also a matter that is determined mainly by how the patterns are arranged, by which is the top and which the bottom or drag side, the manner of drawing, and provisions for avoiding dirt and slag.

Fourth.—Cores, where used, how vented, how supported in the mould, and I will add how made, because cores that are of an irregular form are often more expensive than external moulds, including the patterns. The expense of patterns is often greatly reduced, but is sometimes increased, by the use of cores, which may be employed to cheapen patterns, add to their durability, or to ensure sound castings.

Fifth.—Shrinkage; the allowance that has to be made for the contraction of castings in cooling, in other words, the difference between the size of a pattern and the size of the casting. This is a simple matter apparently, which may be provided for in allowing a certain amount of shrinkage in all directions, but when the inequalities of shrinkage both as to time and degree are taken into account, the allowance to be made becomes a problem of no little complication.

Sixth.—Inherent, or cooling strains, that may either spring and warp castings, or weaken them by maintained tension in certain parts—a condition that often requires a disposition of the metal quite different from what working strains demand.

Seventh.—Draught, the bevel or inclination on the sides of patterns to allow them to be withdrawn from the moulds without dragging or breaking the sand.

Eighth.—Rapping plates, draw plates, and lifting irons for drawing the patterns out of the moulds; fallow and match boards, with other details that are peculiar to patterns, and have no counterparts, neither in names nor uses, outside the foundry.

This makes a statement in brief of what comprehends a knowledge of pattern-making, and what must be understood not only by pattern-makers, but also by mechanical engineers who undertake to design machinery or manage its construction successfully.

As to the manner of cutting out or planing up the lumber for patterns, and the manner of framing them together, it is useless to devote space to the subject here; one hour's practical observation in a pattern-shop, and another hour spent in examining different kinds of patterns, is worth more to the apprentice than a whole volume written to explain how these last-named operations are performed. A pattern, unless finished with paint or opaque varnish, will show the manner in which the wood is disposed in framing the parts together.

I will now proceed to review these conditions or principles in pattern-making and casting in a more detailed way, furnishing as far as possible reasons for different modes of constructing patterns, and the various plans of moulding and casting.

In regard to the character or quality of wood patterns, they can be made, as already stated, at greater or less expense, and if necessary, capable of almost any degree of endurance. The writer has examined patterns which had been used more than two hundred times, and were apparently good for an equal amount of use. Such patterns are expensive in their first cost, but are the cheapest in the end, if they are to be employed for a large number of castings. Patterns for special pieces, or such as are to be used for a few times only, do not require to be strong nor expensive, yet with patterns, as with everything else pertaining to machinery, the safest plan is to err on the side of strength.

For pulleys, gear wheels, or other standard parts of machinery which are not likely to be modified or changed, iron patterns are preferable; patterns for gear wheels and pulleys, when made of wood, aside from their liability to spring and warp, cannot be made sufficiently strong to withstand foundry use; besides, the greatest accuracy that can be attained, even by metal patterns, is far from producing true castings, especially for tooth wheels. The more perfect patterns are, the less rapping is required in drawing them; and the less rapping done, the more perfect castings will be.

The most perfect castings for gear wheels and pulleys and other pieces which can be so moulded, are made by drawing the patterns through templates without rapping. These templates are simply plates of metal perforated so that the pattern can be forced through them by screws or levers, leaving the sand intact. Such templates are expensive to begin with, because of the accurate fitting that is required, especially around the teeth of wheels, and the mechanism that is required in drawing the patterns, but when a large number of pieces are to be made from one pattern, such as gear wheels and pulleys, the saving of labour will soon pay for the templates and machinery required, to say nothing of the saving of metal, which often amounts to ten per cent., and the increased value of the castings because of their accuracy.

Mr Ransome of Ipswich, England, where this system of template moulding originated, has invented a process of fitting templates for gear wheels and other kinds of casting by pouring melted white metal around to mould the fit instead of cutting it through the templates; this effects a great saving in expense, and answers in many cases quite as well as the old plan.

The expense of forming pattern-moulds may be considered as divided between the foundry and pattern-shop. What a pattern-maker saves a moulder may lose, and what a pattern-maker spends a moulder may save; in other words, there is a point beyond which saving expense in patterns is balanced by extra labour and waste in moulding—a fact that is not generally realised because of inaccurate records of both pattern and foundry work. What is lost or saved by judicious or careless management in the matter of patterns and moulding can only be known to those who are well skilled in both moulding and pattern-making. A moulder may cut all the

fillets in a mould with a trowel; he may stop off, fill up, and print in, to save pattern-work, but it is only expedient to do so when it costs very much less than to prepare proper patterns, because patching and cutting in moulds seldom improves them.

The reader may notice how everything pertaining to patterns and moulding resolves itself into a matter of judgment on the part of workmen, and how difficult it would be to apply general rules.

The arrangement of patterns with reference to having certain parts of castings solid and clean is an important matter, yet one that is comparatively easy to understand. Supposing the iron in a mould to be in a melted state, and to contain, as it always must, loose sand and 'scruff,' and that the weight of the dirt is to melted iron as the weight of cork is to water, it is easy to see where this dirt would lodge, and where it would be found in the castings. The top of a mould or cope, as it is called, contains the dirt, while the bottom or drag side is generally clean and sound: the rule is to arrange patterns so that the surfaces to be finished will come on the bottom or drag side.

Expedients to avoid dirt in such castings as are to be finished all over or on two sides are various. Careful moulding to avoid loose sand and washing is the first requisite; sinking heads, that rise above the moulds, are commonly employed when castings are of a form which allows the dirt to collect at one point. Moulds for sinking heads are formed by moulders as a rule, but are sometimes provided for by the patterns.

The quality of castings is governed by a great many things besides what have been named, such as the manner of gating or flowing the metal into the moulds, the temperature and quality of the iron, the temperature and character of the mould—things which any skilled foundryman will take pleasure in explaining in answer to courteous and proper questions.

Cores are employed mainly for what may be termed the displacement of metal in moulds. There is no clear line of distinction between cores and moulds, as founding is now conducted; cores may be of green sand, and made to surround the exterior of a piece, as well as to make perforations or to form recesses within it. The term 'core,' in its technical sense, means dried moulds, as distinguished from green sand. Wheels or other castings are said to be cast in cores when the moulds are made in pieces and dried. Supporting and venting cores, and

their expansion, are conditions to which especial attention is called. When a core is surrounded with hot metal, it gives off, because of moisture and the burning of the 'wash,' a large amount of gas which must have free means of escape. In the arrangement of cores, therefore, attention must be had to some means of venting, which is generally attained by allowing them to project through the sides of the mould and communicate with the air outside.

An apprentice may get a clear idea of this venting process by inspecting tubular core barrels, such as are employed in moulding pipes or hollow columns, or by examining ordinary cores about a foundry. Provision of some kind to 'carry off the vent,' as it is termed by moulders, will be found in every case. The venting of moulds is even more important than venting cores, because core vents only carry off gas generated within the core itself, while the gas from its exterior surface, and from the whole mould, has to find means of escaping rapidly from the flasks when the hot metal enters.

A learner will no doubt wonder why sand is used for moulding, instead of some more adhesive material like clay. If he is not too fastidious for the experiment, and will apply a lump of damp moulding sand to his mouth and blow his breath through the mass, the query will be solved. If it were not for the porous nature of sand-moulds they would be blown to pieces as soon as the hot metal entered them; not only because of the mechanical expansion of the gas, but often from explosion by combustion. Gas jets from moulds, as may be seen at any time when castings are poured, will take fire and burn the same as illuminating gas.

If it were not for securing vent for gas, moulds could be made from plastic material so as to produce fine castings with clear sharp outlines.

The means of supporting cores must be devised, or at least understood, by pattern-makers; these supports consist of 'prints' and 'anchors.' Prints are extensions of the cores, which project through the casting and extend into the sides of the mould, to be held by the sand or by the flask. The prints of cores have duplicates on the patterns, called core prints, which are, or should be, of a different colour from the patterns, so as to distinguish one from the other. The amount of surface required to support cores is dependent upon their weight, or rather upon their cubic

contents, because the weight of a core is but a trifling matter compared to its floating force when surrounded by melted metal. An apprentice in studying devices for supporting cores must remember that the main force required is to hold them down, and not to bear their weight. The floating force of a core is as the difference between its weight and that of a solid of metal of the same size—a matter moulders often forget to consider. It is often impossible, from the nature of castings, to have prints large enough to support the cores, and it is then effected by anchors, pieces of iron that stand like braces between the cores and the flasks or pieces of iron imbedded in the sand to receive the strain of the anchors.

In constructing patterns where it is optional whether to employ cores or not, and in preparing drawings for castings which may have either a ribbed or a cored section, it is nearly always best to employ cores. The usual estimate of the difference between the cost of moulding rib and cored sections, as well as of skeleton and cored patterns, is wrong. The expense of cores is often balanced by the advantage of having an 'open mould,' that is accessible for repairs or facing, and by the greater durability and convenience of the solid patterns. Taking, for example, a column, or box frame for machinery, that might be made either with a rib or a cored section, it would at first thought seem that patterns for a cored casting would cost much more by reason of the core-boxes; but it must be remembered that in most patterns labour is the principal expense, and what is lost in the extra lumber required for a core-box or in making a solid pattern is in many cases more than represented in the greater amount of labour required to construct a rib pattern.

Cores expand when heated, and require an allowance in their dimensions the reverse from patterns; this is especially the case when the cores are made upon iron frames. For cylindrical cores less than six inches diameter, or less than two feet long, expansion need not be taken into account by pattern-makers, but for large cores careful calculation is required. The expansion of cores is as the amount of heat imparted to them, and the amount of heat taken up is dependent upon the quantity of metal that may surround the core and its conducting power.

Shrinkage, or the contraction of castings in cooling, is provided for by adding from one-tenth to one-eighth of an inch to each foot in the dimensions of patterns. This is a simple matter, and

is accomplished by employing a shrink rule in laying down pattern-drawings from the figured dimensions of the finished work; such rules are about one-hundredth part longer than the standard scale.

This matter of shrinkage is indeed the only condition in pattern-making which is governed by anything near a constant rule, and even shrinkage requires sometimes to be varied to suit special cases. For small patterns whose dimensions do not exceed one foot in any direction, rapping will generally make up for shrinkage, and no allowance is required in the patterns, but pattern-makers are so partial to the rule of shrinkage, as the only constant one in their work, that they are averse to admitting exceptions, and usually keep to the shrink rule for all pieces, whether large or small.

Inherent or cooling strains in castings is much more intricate than shrinkage: it is, in fact, one of the most uncertain and obscure matters that pattern-makers and moulders have to contend with. Inherent strains may weaken castings, or cause them to break while cooling, or sometimes even after they are finished; and in many kinds of works such strains must be carefully guarded against, both in the preparation of designs and the arrangement of patterns, especially for wheels and pulleys with spokes, and for struts or braces with both ends fixed. The main difficulty resulting from cooling strains, however, is that of castings being warped and sprung; this difficulty is continually present in the foundry and machine-shop, and there is perhaps no problem in the whole range of mechanical manipulation of which there exists more diversity of opinion and practice than of means to preventing the springing of castings. This being the case, an apprentice can hardly hope for much information here. There is no doubt of springing and strains in castings being the result of constant causes that might be fully understood if it were not for the ever-changing conditions which exist in casting, both as to the form of pieces, the temperature and quality of metal, mode of cooling, and so on.

Castings are of course sprung by the action of unequal strains, caused by one part cooling or 'setting' sooner than another. That far all is clear, but the next step takes us into the dark. What are the various conditions which induce irregular cooling, and how is it to be avoided?

Irregularity of cooling may be the result of unequal conduct-

ing power in different parts of a mould or cores, or it may be from the varying dimensions of the castings, which contain heat as their thickness, and give it off in the same ratio. As a rule, the drag or bottom side of a casting cools first, especially if a mould rests on the ground, and there is not much sand between the castings and the earth; this is a common cause of unequal cooling, especially in large flat pieces. Air being a bad conductor of heat, and the sand usually thin on the cope or top side, the result is that the top of moulds remain quite hot, while at the bottom the earth, being a good conductor, carries off the heat and cools that side first, so that the iron 'sets' first on the bottom, afterwards cooling and contracting on the top, so that castings are warped and left with inherent strains.

These are but a few of many influences which tend to irregular cooling, and are described with a view of giving a clue from which other causes may be traced out. The want of uniformity in sections which tends to irregular cooling can often be avoided without much loss by a disposition of the metal with reference to cooling strains. This, so far as the extra metal required to give uniformity to or to balance the different sides of a casting, is a waste which engineers are sometimes loth to consent to, and often neglect in designs for moulded parts; yet, as before said, the difficulty of irregular cooling can in a great degree be counteracted by a proper distribution of the metal, without wasting, if the matter is properly understood. No one is prepared to make designs for castings who has not studied the subject of cooling strains as thoroughly as possible, from practical examples as well as by theoretical deductions.

Draught, or the taper required to allow patterns to be drawn readily, is another of those indefinite conditions in pattern-making that must be constantly decided by judgment and experience. It is not uncommon to find rules for the draught of patterns laid down in books, but it would be difficult to find such rules applied. The draught may be one-sixteenth of an inch to each foot of depth, or it may be one inch to a foot of depth, or there may be no draught whatever. Any rule, considered aside from specified conditions, will only confuse a learner. The only plan to understand the proper amount of draught for patterns is to study the matter in connection with patterns and foundry operations.

Patterns that are deep, and for castings that require to be parallel or square when finished, are made with the least possible

amount of draught. If a pattern is a plain form, that affords facilities for lifting or drawing, it may be drawn without taper if its sides are smooth and well finished. Pieces that are shallow and moulded often should, as a matter of convenience, have as much taper as possible; and as the quantity of draught can be as the depth of a pattern, we frequently see them made with a taper that exceeds one inch to the foot of depth.

Moulders generally rap patterns as much as they will stand, often more than they will stand; and in providing for draught it is necessary to take these customs into account. There is no use in making provision to save rapping unless the rapping is to be omitted.

Rapping plates, draw-irons, and other details of pattern-making are soon understood by observation. Perhaps the most useful suggestion which can be given in reference to draw-irons is to say they should be set on the under or bottom side of patterns, instead of on the top, where they are generally placed. A draw-plate set in this way, with a hole bored through the pattern so as to insert draw-irons from the top, cannot pull off, which it is apt to do if set on the top side. Every pattern no matter how small, should be ironed, unless it is some trifling piece, with dowel-pins, draw and rapping plates. If a system of draw-irons is not rigidly carried out, moulders will not trouble themselves to take care of patterns.

In conclusion, I will say on the subject of patterns and castings, that a learner must depend mainly upon what he can see and what is explained to him in the pattern-shop and foundry. He need never fear an uncivil answer to a proper question, applied at the right time and place. Mechanics who have enough knowledge to give useful information of their business, have invariably the courtesy and good sense to impart such information to those who require it.

An apprentice should never ask questions about simple and obvious matters, or about such things as he can easily learn by his own efforts. The more difficult a question is, the more pleasure a skilled man will take in answering it. In short, a learner should carefully consider questions before asking them. A good plan is to write them down, and when information is wanted about casting, never go to a foundry to interrupt a manager or moulder at melting time, nor in the morning, when no one wants to be annoyed with questions.

I will, in connection with this subject of patterns and castings, suggest a plan of learning especially applicable in such cases, that of adopting a habit of imagining the manner of moulding, and the kind of pattern used in producing each casting that comes under notice. Such a habit becomes easy and natural in a short time, and is a sure means of acquiring an extended knowledge of patterns and moulding.

A pattern-maker no sooner sees a casting than he imagines the kind of pattern employed in moulding it; a moulder will imagine the plan of moulding and casting a piece; while an engineer will criticise the arrangement, proportions, adaptation, and general design, and if skilled, as he ought to be, will also detect at a glance any useless expense in patterns or moulding.

(1.) Why cannot the regular working drawings of a machine be employed to construct patterns by?—(2.) What should determine the quality or durability of patterns?—(3.) How can the arrangement of patterns affect certain parts of a casting?—(4.) What means can be employed to avoid inherent strain in castings?—(5.) Why is the top of a casting less sound than the bottom or drag side?—(6.) What are cores employed for?—(7.) What is meant by venting a mould?—Explain the difference between green and dry sand mouldings.—(8.) Why is sand employed for moulds?—(10.) What generally causes the disarrangement of cores in casting?—(11.) Why are castings often sprung or crooked?—(12.) What should determine the amount of draught given to patterns?—(13). What are the means generally adopted to avoid cooling strains in castings?

CHAPTER XXIII.

FORGING.

Workshop processes which are capable of being systematised are the most easy to learn. When a process is reduced to a system it is no longer a subject of special knowledge, but comes within general rules and principles, which enable a learner to use his reasoning powers to a greater extent in mastering it.

To this proposition another may be added, that shop processes may be systematised or not, as they consist in duplication, or the

performance of certain operations repeatedly in the same manner. It has been shown in the case of patterns that there could be no fixed rules as to their quality or the mode of constructing them, and that how to construct patterns is a matter of special knowledge and skill.

These rules apply to forging, but in a different way from other processes. Unlike pattern-making or casting, the general processes in forging are uniform; and still more unlike pattern-making or casting, there is a measurable uniformity in the articles produced, at least in machine-forging, where bolts, screws, and shafts are continually duplicated.

A peculiarity of forging is that it is a kind of hand process, where the judgment must continually direct the operations, one blow determining the next, and while pieces forged may be duplicates, there is a lack of uniformity in the manner of producing them. Pieces may be shaped at a white welding heat or at a low red heat, by one or two strong blows or by a dozen lighter blows, the whole being governed by the circumstances of the work as it progresses. A smith may not throughout a whole day repeat an operation precisely in the same manner, nor can he, at the beginning of an operation, tell the length of time required to execute it, nor even the precise manner in which he will perform it. Such conditions are peculiar, and apply to forging alone.

I think proper to point out these peculiarities, not so much from any importance they may have in themselves, but to suggest critical investigation, and to dissipate any preconceived opinions of forging being a simple matter, easy to learn, and involving only commonplace operations.

The first impressions an apprentice forms of the smith-shop as a department of an engineering establishment is that it is a black, sooty, dirty place, where a kind of rough unskilled labour is performed—a department which does not demand much attention. How far this estimate is wrong will appear in after years, when experience has demonstrated the intricacies and difficulties of forging, and when he finds the skill in this department is more difficult to obtain, and costs more relatively than in any other. Forging as a branch of work requires, in fact, the highest skill, and is one where the operation continually depends upon the judgment of the workman, which neither power nor machines can to any extent supplant. Dirt, hard labour, and heat deter men from learning to forge, and create a preference for the finishing

shop, which in most places makes a disproportion between the number of smiths and finishers.

Forging as a process in machine-making includes the forming and shaping of the malleable parts of machinery, welding or joining pieces together, the preparation of implements for forging and finishing, tempering of steel tools, and usually case-hardening.

Considered as a process, forging may be said to relate to shaping malleable material by blows or compression when it is rendered soft by heating. So far as hand-tools and the ordinary hand operations in forging, there can be nothing said that will be of much use to a learner. In all countries, and for centuries past, hand implements for forging have remained quite the same; and one has only to visit any machine forging-shop to see samples and types of standard tools. There is no use in describing tongs, swages, anvils, punches, and chisels, when there is nothing in their form nor use that may not be seen at a glance; but tools and machines for the application of motive power in forging processes deserve more careful notice.

Forging plant consists of rolling mills, trip-hammers, steam-hammers, drops, and punches, with furnaces, hearths, and blowing apparatus for heating. A general characteristic of all forging machines is that of a great force acting throughout a short distance. Very few machines, except the largest hammers, exceed a half-inch of working range, and in average operations not one-tenth of an inch.

These conditions of short range and great force are best attained by what may be termed percussion, and by machines which act by blows instead of positive and gradual pressure; hence we find that hand and power hammers are the most common tools among those of the smith-shop.

To exert a powerful force acting through but a short distance, percussive devices are much more effective and simple than those acting by maintained or direct pressure. A hammer-head may give a blow equal to many tons by its momentum, and absorb the reactive force which is equal to the blow; but if an equal force was to be exerted by screws, levers, or hydraulic apparatus, we can easily see that an abutment would be required to withstand the reactive force, and that such an abutment would require a strength perhaps beyond what ingenuity could devise.

This principle is somewhat obscure, and the nature of percussive forces not generally considered—a matter which may be illustra-

ted by considering the action of a simple hand-hammer. Few people, in witnessing the use of a hammer, or in using one themselves, ever think of it as an engine giving out tons of force, concentrating and applying power by functions which, if performed by other mechanism, would involve trains of gearing, levers, or screws; and that such mechanism, if employed instead of a hammer, must lack that important function of applying force in any direction as the will and hands may direct. A simple hand-hammer is in the abstract one of the most intricate of mechanical agents—that is, its action is more difficult to analyse than that of many complex machines involving trains of mechanism; yet our familiarity with hammers causes this fact to be overlooked, and the hammer has even been denied a place among those mechanical contrivances to which there has been applied the name of "mechanical powers."

Let the reader compare a hammer with a wheel and axle, inclined plane, screw, or lever, as an agent for concentrating and applying power, noting the principles of its action first, and then considering its universal use, and he will conclude that, if there is a mechanical device that comprehends distinct principles, that device is the common hammer. It seems, indeed, to be one of those provisions to meet a human necessity, and without which mechanical industry could not be carried on. In the manipulation of nearly every kind of material, the hammer is continually necessary in order to exert a force beyond what the hands may do, unaided by mechanism to multiply their force. A carpenter in driving a spike requires a force of from one to two tons; a blacksmith requires a force of from five pounds to five tons to meet the requirements of his work; a stonemason applies a force of from one hundred to one thousand pounds in driving the edge of his tools; chipping, calking, in fact nearly all mechanical operations, consist more or less in blows, such blows being the application of accumulated force expended throughout a limited distance.

Considered as a mechanical agent, a hammer concentrates the power of the arms, and applies it in a manner that meets the requirements of various purposes. If great force is required, a long swing and slow blows accomplish tons; if but little force is required, a short swing and rapid blows will serve—the degree of force being not only continually at control, but also the direction in which it is applied. Other mechanism, if employed instead of

hammers to perform a similar purpose, would require to be complicated machines, and act in but one direction or in one plane.

These remarks upon hammers are not introduced here as a matter of curiosity, nor with any intention of following mechanical principles beyond where they will explain actual manipulation, but as a means of directing attention to percussive acting machines generally, with which forging processes, as before explained, have an intimate connection.

Machines and tools operating by percussive action, although they comprise a numerous class, and are applied in nearly all mechanical operations, have never received that amount of attention in text-books which the importance of the machines and their extensive use calls for. Such machines have not even been set off as a class and treated of separately, although the distinction is quite clear between machines with percussive action, and those with what may be termed direct action, both in the manner of operating and in the general plans of construction. There is, of course, no lack of formulæ for determining the measure of force, and computing the dynamic effect of percussive machines acting against a measured or assumed resistance, and so on; but this is not what is meant. There are certain conditions in the operation of machines, such as the strains which fall upon supporting frames, the effect produced upon malleable material when struck or pressed, and more especially of conditions which may render percussive or positive acting machines applicable to certain purposes; but little explanation has been given which is of value to practical men.

Machines and tools that operate by blows, such as hammers and drops, produce effect by the impact of a moving mass by force accumulated throughout a long range, and expending the sum of this accumulated force on an object. The reactive force not being communicated to nor resisted by the machine frames, is absorbed by the inertia of the mass which gave the blow; the machinery required in such operations being only a weight, with means to guide or direct it, and mechanism for connection with motive power. A hand-hammer, for example, accumulates and applies the force of the arm, and performs all the functions of a train of mechanism, yet consists only of a block of metal and a handle to guide it.

Machines with direct action, such as punches, shears, or rolls, require first a train of mechanism of some kind to reduce the

motion from the driving power so as to attain force; and secondly, this force must be balanced or resisted by strong framing, shafts, and bearings. A punching-machine, for example, must have framing strong enough to resist a thrust equal to the force applied to the work; hence the frames of such machines are always a huge mass, disposed in the most advantageous way to meet and resist this reactive force, while the main details of a drop-machine capable of exerting an equal force consist only of a block and a pair of guides to direct its course.

Leaving out problems of mechanism in forging machines, the adaptation of pressing or percussive processes is governed mainly by the size and consequent inertia of the pieces acted upon. In order to produce a proper effect, that is, to start the particles of a piece throughout its whole depth at each blow, a certain proportion between a hammer and the piece acted upon must be maintained. For heavy forging, this principle has led to the construction of enormous hammers for the performance of such work as no pressing machinery can be made strong enough to execute, although the action of such machinery in other respects would best suit the conditions of the work. The greater share of forging processes may be performed by either blows or compression, and no doubt the latter process is the best in most cases. Yet, as before explained, machinery to act by pressure is much more complicated and expensive than hammers and drops. The tendency in practice is, however, to a more extensive employment of press-forging processes.

(1.) What peculiarity belongs to the operation of forging to distinguish it from most others?—(2.) Describe in a general way what forging operations consist in.—(3.) Name some machines having percussive action.—(4.) What may this principle of operating have to do with the framing of a machine?—(5.) If a steam-hammer were employed as a punching-machine, what changes would be required in its framing?—(6.) Explain the functions performed by a hand-hammer.

CHAPTER XXIV.

TRIP-HAMMERS.

TRIP-HAMMERS employed in forging bear a close analogy to, and were no doubt first suggested by, hand-hammers. Being the oldest of power-forging machines, and extensively employed, it will be proper to notice trip-hammers before steam-hammers.

As remarked in the case of other machines treated of, there is no use of describing the mechanism of trip-hammers; it is presumed that every engineer apprentice has seen trip-hammers, or can do so; and the plan here is to deal especially with what he cannot see, and would not be likely to learn by casual observation.

One of the peculiarities of trip-hammers as machines is the mechanical difficulties in connecting them with the driving power, especially in cases where there are a number of hammers to be driven from one shaft.

The sudden and varied resistance to line shafts tends to loosen couplings, destroy gearing, and produce sudden strains that are unknown in other cases; and shafting arranged with the usual proportions for transmitting power will soon fail if applied to driving trip-hammers. Rigid connections or metal attachments are impracticable, and a slipping belt arranged so as to have the tension varied at will is the usual and almost the only successful means of transmitting power to hammers. The motion of trip-hammers is a curious problem; a head and die weighing, together with the irons for attaching them, one hundred pounds, will, with a helve eight feet long, strike from two to three hundred blows a minute. This speed exceeds anything that could be attained by a direct reciprocal motion given to the hammer-head by a crank, and far exceeds any rate of speed that would be assumed from theoretical inference. The hammer-helve being of wood, is elastic, and acts like a vibrating spring, its vibrations keeping in unison with the speed of the tripping points. The whole machine, in fact, must be constructed upon a principle of elasticity throughout, and in this regard stands as an exception to almost every other known machine. The framing for supporting the trunnions, which one without experience would suppose should be very rigid and solid, is found to answer best when composed of timber, and still better when this timber is

laid up in a manner that allows the structure to spring and yield. Starting at the dies, and following back through the details of a trip-hammer to the driving power, the apprentice may note how many parts contribute to this principle of elasticity: First—the wooden helve, both in front of and behind the trunnion; next—the trunnion bar, which is usually a flat section mounted on pivot points; third—the elasticity of the framing called the 'husk,' and finally the frictional belt. This will convey an idea of the elasticity required in connecting the hammer-head with the driving power, a matter to be borne in mind, as it will be again referred to.

Another peculiar feature in trip-hammers is the rapidity with which crystallisation takes place in the attachments for holding the die blocks to the helves, where no elastic medium can be interposed to break the concussion of the dies. Bolts to pass through the helve, although made from the most fibrous Swedish iron, will on some kinds of work not last for more than ten days' use, and often break in a single day. The safest mode of attaching die blocks, and the one most common, is to forge them solid, with an eye or a band to surround the end of the helve.

At the risk of laying down a proposition not warranted by science, I will mention, in connection with this matter of crystallisation, that metal when disposed in the form of a ring, for some strange reason seems to evade the influences which produce crystalline change. A hand-hammer, for example, may be worn away and remain fibrous; the links of chains and the tires of waggon wheels do not become crystallised; even the tires on locomotive wheels seem to withstand this influence, although the conditions of their use are such as to promote crystallisation.

Among exceptions to the ordinary plans of constructing trip-hammers, may be mentioned those employed in the American Armoury at Springfield, U.S., where small hammers with rigid frames and helves, the latter thirty inches long, forged from Lowmoor iron, are run at a speed of 'six hundred blows a minute.' As an example, however, they prove the necessity for elasticity, because the helves and other parts have to be often renewed, although the duty performed is very light, such as making small screws.

(1.) What limits the speed at which the reciprocating parts of machines may act?—(2.) What is the nature of reciprocal motion pro-

duced by cranks?—3. Can reciprocating movement be uniform in such machines as power-hammers, saws, or pumps?—4. What effect as to the rate of movement is produced by the elastic connections of a trip-hammer?

CHAPTER XXV.

CRANK-HAMMERS.

POWER-HAMMERS operated by crank motion, adapted to the lighter kinds of work, are now commonly met with in the forging-shops of engineering establishments. They are usually of very simple construction, and I will mention only two points in regard to such hammers, which might be overlooked by an apprentice in examining them.

The faces of the dies remain parallel, no matter how large the piece may be that is operated upon, while with a trip-hammer, the top die moves in an arc described from the trunnions of the helve, and the faces of the dies can only be parallel when in one position, or when operating on pieces of a certain depth. This feature of parallel movement with the dies of crank-hammers is of great importance on some kinds of work, and especially so for machine-forgings where the size or depth of the work is continually being varied.

A second point to be noticed in hammers of this class is the nature of the connection with the driving power. In all cases there will be found an equivalent for the elastic helve of the trip-hammer—either air cylinders, deflecting springs, or other yielding attachments,—interposed between the crank and the hammer-head, also a slipping frictional belt or frictional clutches for driving, as in the case of trip-hammers.

CHAPTER XXVI.

STEAM-HAMMERS.

The direct application of steam to forging-hammers is without doubt the greatest improvement that has ever been made in forging machinery; not only has it simplified operations that were carried on before this invention, but has added many branches, and extended the art of forging to purposes which could never have been attained except for the steam-hammer.

The general principles of hammer-action, so far as already explained, apply as well to hammers operated by direct steam; and a learner, in forming a conception of steam-hammers, must not fall into the common error of regarding them as machines distinct from other hammers, or as operating upon new principles. A steam-hammer is nothing more than the common hammer driven by a new medium, a hammer receiving power through the agency of steam instead of belts, shafts, and cranks. The steam-hammer in its most improved form is so perfectly adapted to fill the different conditions required in power-hammering, that there seems nothing left to be desired.

Keeping in view what has been said about an elastic connection for transmitting motion and power to hammers, and cushioning the vibratory or reciprocating parts, it will be seen that steam as a driving medium for hammers fills the following conditions:—

First.—The power is connected to the hammer by means of the least possible mechanism, consisting only of a cylinder, a piston, and slide valve, induction pipe and throttle valve; these few details taking the place of a steam-engine, shafts, belts, cranks, springs, pulleys, gearing, in short, all such details as are required between the hammer-head and the steam-boiler in the case of trip-hammers or crank-hammers.

Second.—The steam establishes the greatest possible elasticity in the connection between a hammer and the driving power, and at the same time serves to cushion the blows at both the top and bottom of the stroke, or on the top only, as occasion may require.

Third.—Each blow given is an independent operation, and

can be repeated at will, while in other hammers such changes can only be made throughout a series of blows by gradually increasing or diminishing their force.

Fourth.—There is no direct connection between the moving parts of the hammer and the framing, except lateral guides for the hammer-head; the steam being interposed as a cushion in the line of motion, this reduces the required strength and weight of the framing to a minimum, and avoids positive strains and concussion.

Fifth.—The range and power of the blows, as well as the time in which they are delivered, is controlled at will; this constitutes the greatest distinction between steam and other hammers, and the particular advantage which has led to their extended use.

Sixth.—Power can be transmitted to steam-hammers through a small pipe, which may be carried in any direction, and for almost any distance, at a moderate expense, so that hammers may be placed in such positions as will best accommodate the work, and without reference to shafts or other machinery.

Seventh.—There is no waste of power by slipping belts or other frictional contrivances to graduate motion; and finally, there is no machinery to be kept in motion when the hammer is not at work.

Keeping these various points in mind, an apprentice will derive both pleasure and advantage from tracing their application in steam-hammers, which may come under notice, and various modifications of the mechanism will only render investigation more interesting.

One thing more must be noticed, a matter of some intricacy, but without which, all that has been explained would fail to give a proper idea of steam-hammer-action. The valve motions are alluded to.

Steam-hammers are divided into two classes—one having the valves moved by hand, and the other class with automatic valve movement.

The action of steam-hammers may also be divided into what is termed elastic blows, and dead blows.

In operating by elastic blows, the steam piston is cushioned at both the up and down stroke, and the action of a steam-hammer corresponds to that of a helve trip-hammer, the steam filling the office of a vibrating spring; in this case a hammer

gives a quick rebounding blow, the momentum being only in part spent upon the work, and partly arrested by cushioning on the steam in the bottom of the cylinder under the piston.

Aside from the greater rapidity with which a hammer may operate when working on this principle, there is nothing gained, and much lost; and as this kind of action is imperative in any hammer that has a 'maintained or positive connection' between its reciprocating parts and the valve, it is perhaps fair to infer that one reason why most automatic hammers act with elastic blows is either because of a want of knowledge as to a proper valve arrangement, or the mechanical difficulties in arranging valve gear to produce dead blows.

In working with dead blows, no steam is admitted under the piston until the hammer has finished its down stroke, and expended its momentum upon the work. So different is the effect produced by these two plans of operating, that on most kinds of work a hammer of fifty pounds, working with dead blows, will perform the same duty that one of a hundred pounds will, when acting by elastic or cushioned blows.

This difference between dead and elastic strokes is so important that it has served to keep hand-moved valves in use in many cases where much could be gained by employing automatic acting hammers.

Some makers of steam-hammers have so perfected the automatic class, that they may be instantly changed so as to work with either dead blows or elastic blows at pleasure, thereby combining all the advantages of both principles. This brings the steam-hammer where it is hard to imagine a want of farther improvement.

The valve géaring of automatic steam-hammers to fill the two conditions of allowing a dead or an elastic blow, furnishes one of the most interesting examples of mechanical combination.

It was stated that to give a dead or stamp stroke, the valve must move and admit steam beneath the piston after the hammer has made a blow and stopped on the work, and that such a movement of the valve could not be imparted by any maintained connection between the hammer-head and valve. This problem is met by connecting the drop or hammer-head with some mechanism which will, by reason of its momentum, continue to 'move after the hammer-head stops.' This mechanism may consist of various devices. Messrs Massey in England, and

Messrs Ferris & Miles in America employ a swinging wiper bar, which is by reason of its weight or inertia retarded, and does not follow the hammer-head closely on the down stroke, but swings into contact and opens the valve after the hammer has come to a full stop.

By holding this wiper bar continuously in contact with the hammer-drop, elastic or rebounding blows are given, and by adding weight in certain positions to the wiper bar its motion is so retarded that a hammer will act as a stamp or drop. A German firm employs the concussion of the blow to disengage valve gear, so that it may fall and effect this after movement of the valves. Other engineers effect the same end by employing the momentum of the valve itself, having it connected to the drop by a slotted or yielding connection, which allows an independent movement of the valve after the hammer stops.

(1.) In comparing steam-hammers with trip or crank hammers what mechanism does steam supplant or represent?—(2.) What can be called the chief distinction between steam and other hammers?—(3.) Under what circumstances is an automatic valve motion desirable?—(4.) Why is a dead or uncushioned blow most effective?—(5.) Will a hammer operate with air the same as with steam?

CHAPTER XXVII.

COMPOUND HAMMERS.

Another principle to be noticed in connection with hammers and forging processes is that of the inertia of the piece operated upon—a matter of no little importance in the heavier kinds of work.

When a piece is placed on an anvil, and struck on the top side with a certain force, the bottom or anvil side of the piece does not receive an equal force. A share of the blow is absorbed by the inertia of the piece struck, and the effect on the bottom side is, theoretically, as the force of the blow, less the cushioning effect and the inertia of the pieces acted upon.

In practice this difference of effect on the top and bottom, or between the anvil and hammer sides of a piece, is much greater than would be supposed. The yielding of the soft metal on the top cushions the blow and protects the under side from the force. The effect produced by a blow struck upon hot iron cannot be estimated by the force of the blow; it requires, to use a technical term, a certain amount of force to "start" the iron, and anything less than this force has but little effect in moving the particles and changing the form of a piece.

From this it may be seen that there must occur a great loss of power in operating on large pieces, for whatever force is absorbed by inertia has no effect on the underside. By watching a smith using a hand hammer it will be seen that whenever a piece operated upon is heavier than the hammer employed, but little if any effect is produced on the anvil or bottom surface, nor is this loss of effect the only one. The expense of heating, which generally exceeds that of shaping forgings, is directly as the amount of shaping that may be done at each heat; and consequently, if the two sides of a piece, instead of one, can be equally acted upon, one-half the heating will be saved.

Another object gained by equal action on both sides of large pieces is the quality of the forgings produced, which is generally improved by the rapidity of the shaping processes, and injured by too frequent heating.

The loss of effect by the inertia of the pieces acted upon increases with the weight of the work; not only the loss of power, but also the expense of heating increases with the size of the pieces. There is, however, such a difference in the mechanical conditions between light and heavy forging that for any but a heavy class of work there would be more lost than gained in attempting to operate on both sides of pieces at the same time.

To attain a double effect, and avoid the loss pointed out, Mr Ramsbottom designed what may be called compound hammers, consisting of two independent heads or rams moving in opposite directions, and acting simultaneously upon pieces held between them.

It would be inferred that the arrangement of these double acting hammers must necessarily be complicated and expensive, but the contrary is the fact. The rams are simply two masses of iron mounted on wheels that run on ways, like a truck, and the im-

pact of the hammers, so far as not absorbed in the work, is neutralised by each other. No shock or jar is communicated to framing or foundations as in the case of single acting hammers that have fixed anvils. The same rule applies in the back stroke of the hammers as the links which move them are connected together at the centre, where the power is applied at right angles to the line of the hammer movement. The links connecting the two hammers constitute, in effect, a toggle joint, the steam piston being attached where they meet in the centre.

The steam cylinder which moves the hammers is set in the earth at some depth below the plane upon which they move, and even when the heaviest work is done there is no perceptible jar when one is standing near the hammers, as there always is with those which have a vertical movement and are single acting.

(1.) Why is the effect produced different on the top and bottom of a piece when struck by a hammer?—(2.) Why does not a compound hammer create jar and concussion?—(3.) What would be a mechanical difficulty in presenting the material to such hammers?—(4.) Which is most important, speed or weight, in the effect produced on the under side of pieces, when struck by single acting hammers?

CHAPTER XXVIII.

TEMPERING STEEL.

TEMPERING may be called a mystery of the smith-shop; this operation has that attraction which characterises every process that is mysterious, especially such as are connected with, or belong to mechanical manipulation. A strange and perhaps fortunate habit of the mind is to be greatly interested in what is not well understood, and to disregard what is capable of plain demonstration.

An old smith who has stood at the forge for a score of years will take the same interest in tempering processes that a novice will. When a piece is to be tempered which is liable to spring or break, and the risk is great, he will enter upon it with the same zeal and interest that he would have done when learning his trade.

No one has been able to explain clearly why a sudden change of temperature hardens steel, nor why it assumes various shades of colour at different degrees of hardness; we only know the fact, and that steel fortunately has such properties.

Every one who uses tools should understand how to temper them, whether they be for iron or wood. Experiments with tempered tools is the only means of determining the proper degree of hardness, and as smiths, except with their own tools, have to rely upon the explanations of others as to proper hardening, it follows that tempering is generally a source of complaint.

Tempering, as a term, is used to comprehend both hardening and drawing; as a process it depends mainly upon judgment instead of skill, and has no such connection with forging as to be performed by smiths only. Tempering requires a different fire from those employed in forging, and also more care and precision than blacksmiths can exercise, unless there are furnaces and baths especially arranged for tempering tools.

A difficulty which arises in hardening tools is because of the contraction of the steel which takes place in proportion to the change of temperature; and as the time of cooling is in proportion to the thickness or size of a piece, it follows, of course, that there is a great strain and a tendency to break the thinner parts before the thicker parts have time to cool; this strain may take place either from cooling one side first, or more rapidly than another.

The following propositions in regard to tempering, comprehend the main points to be observed:

The permanent contraction of steel in tempering is as the degree of hardness imparted to it by the bath.

The time in which the contraction takes place is as the temperature of the bath and the cross section of the piece; in other words the heat passes off gradually from the surface to the centre.

Thin sections of steel tools being projections from the mass which supports the edges, are cooled first, and if provision is not made to allow for contraction they are torn asunder.

The main point in hardening and the most that can be done to avoid irregular contraction, is to apply the bath so that it will act first and strongest on the thickest parts. If a piece is tapering or in the form of a wedge, the thick end should enter the bath first; a cold chisel for instance that is wide enough to

[illegible] very hard, are [illegible] required in ordi- [illegible]

[illegible] partly of [illegible] hardening [illegible] steel edge at a [illegible] when cooled in [illegible] to a state of rest and correspond [illegible] may be produced by curving [illegible] to the steel side before hardening.

Tools should never be tempered by immersing their edges or cutting parts in the bath, and then allowing the heat to "run down" to attain a proper temper at the edge. I am well aware that this is attacking a general custom, but it is none the less wrong for that reason. Tools so hardened have a gradually diminishing temper from their point or edge, so that no part is properly tempered, and they require continual re-hardening, which spoils the steel; besides, the extreme edge, the only part which is tempered to a proper shade, is usually spoiled by heating and must be ground away to begin with. No lathe-man who has once had a set of tools tempered throughout by slow drawing, either in an oven, or on a hot plate, will ever consent to point hardening afterwards. A plate of iron, two to two and one half inches thick, placed over the top of a tool dressing fire, makes a convenient arrangement for tempering tools, besides adding greatly to the convenience of slow heating, which is almost as important as slow drawing. The writer has

by actual experiment determined that the amount of tool dressing and tempering, to say nothing of time wasted in grinding tools, may in ordinary machine fitting be reduced one-third by "oven tempering."

As to the shades that appear in drawing temper, or tempering it is sometimes called, it is quite useless to repeat any of the old rules about "straw colour, violet, orange, blue," and so on; the learner knows as much after such instruction as before. The shades of temper must be seen to be learned, and as no one is likely to have use for such knowledge before having opportunities to see tempering performed, the following plan is suggested for learning the different shades. Procure eight pieces of cast steel about two inches long by one inch wide and three-eighths of an inch thick, heat them to a high red heat and drop them into a salt bath; preserve one without tempering to show the white shade of extreme hardness, and polish one side of each of the remaining seven pieces; then give them to an experienced workman to be drawn to seven varying shades of temper ranging from the white piece to the dark blue colour of soft steel. On the backs of these pieces labels can be pasted describing the technical names of the shades and the general uses to which tools of corresponding hardness are adapted.

This will form an interesting collection of specimens and accustom the eye to the various tints, which after some experience will be instantly recognised when seen separately.

It may be remarked as a general rule that the hardness of cutting tools is "inverse as the hardness of the material to be cut," which seems anomalous, and no doubt is so, if nothing but the cutting properties of edges is considered; but all cutting edges are subjected to transverse strain, and the amount of this strain is generally as the hardness of the material acted upon; hence the degree of temper has of necessity to be such as to guard against breaking the edges. Tools for cutting wood, for example, can be much harder than for cutting iron, or to state it better, tools for cutting wood are harder than those usually employed for cutting iron; for if iron tools were always as carefully formed and as carefully used as those employed in cutting wood, they could be equally hard.

Forges, pneumatic machinery for blast, machinery for handling large pieces, and other details connected with forging, are easily understood from examples.

(1.) What causes tools to bend or break in hardening?—(2.) What means can be employed to prevent injury to tools in hardening?—(3.) Can the shades of temper be produced on a piece of steel without hardening?—(4.) What forms a limit of hardness for cutting tools?—(5.) What are the objects of steel-laying tools instead of making them of solid steel?

CHAPTER XXIX.

FITTING AND FINISHING.

THE fitting or finishing department of engineering establishments is generally regarded as the main one.

Fitting processes, being the final ones in constructing machinery, are more nearly in connection with its use and application; they consist in the organisation or bringing together the results of other processes carried on in the draughting room, pattern shop, foundry, and smith shop.

To the unskilled, or to those who do not take a comprehensive view of an engineering business as a whole, the finishing and fitting department seems to constitute the whole of machine manufacture—an impression which a learner should guard against, because nothing but a true understanding of the importance and relations of the different divisions of an establishment can enable them to be thoroughly or easily learned.

Finishing, therefore, it must be borne in mind, is but one among several processes, and that the fitting department is but one out of four or more among which attention is to be divided.

Finishing as a process is a secondary and not always an essential one; many parts of machinery are ready for use when forged or cast and do not require fitting; yet a finishing shop must in many respects be considered the leading department of an engineering establishment. Plans, drawings and estimates are always based on finished work, and when the parts have accurate dimensions; hence designs, drawings and estimates may be said to pass through the fitting shop and follow back to the foundry and smith shop, so that finishing, although the last process in the order of the work, is the first one after the drawings in every other sense; even the dimensions in pattern-making which seems farthest removed from finishing, are based upon

fitting dimensions, and to a great extent must be modified by the conditions of finishing.

In casting and forging operations the material is treated while in a heated and expanded condition; the nature of these operations is such that accurate dimensions cannot be attained, so that both forgings and castings require to be made enough larger than their finished dimensions to allow for shrinkage and irregularities. Finishing as a process consists in cutting away this surplus material, and giving accurate dimensions to the parts of machinery when the material is at its natural temperature. Finishing operations being performed as said upon material at its normal temperature permits handling, gauging and fitting together of the parts of machinery, and as nearly all other processes involve heating, finishing may be called the cold processes of metal work. The operations of a fitting shop consist almost entirely of cutting, and grinding or abrading; a proposition that may seem novel, yet these operations comprehend nearly all that is performed in what is called fitting.

Cutting processes may be divided into two classes: cylindrical cutting, as in turning, boring, and drilling, to produce circular forms; and plane cutting, as in planing, shaping, slotting and shearing, to produce plane or rectangular forms. Abrading or grinding processes may be applied to forms of any kind.

To classify further—cutting machines may be divided into those wherein the tools move and the material is fixed, and those wherein the material is moved and the tools fixed, and machines which involve a compound movement of both the tools and the material acted upon.

There is also a distinction between machine and hand cutting that may be noted. In machine cutting it is performed in true geometrical lines, the tools or material being moved by positive guides as in planing and turning; in hand operations, such as filing, scraping or chipping, the tools are moved without positive guidance, and act in irregular lines.

To attempt a generalisation of the operations of the fitting shop in this manner may not seem a very practical means of understanding them, yet the application will be better understood as we go farther on.

Cutting tools include nearly all that are employed in finishing; lathes, planing machines, drilling and boring machines, shaping, slotting and milling machines, come within this class. The

machines named make up what are called standard tools, such as are essential and are employed in all establishments where general machine manufacture is carried on. Such machines are constructed upon principles substantially the same in all countries, and have settled into a tolerably uniform arrangement of movements and parts.

Besides the machine tools named, there are special machines to be found in most works, machines directed to the performance of certain work: by a particular adaptation such machines are rendered more effective, but they are by such adapation unfitted for general purposes.

General engineering work cannot consist in the production of duplicate pieces, nor in operations performed constantly in the same manner as in ordinary manufacturing; hence there has been much effort expended in adapting machines to general purposes —machines, which seldom avoid the objections of combination, pointed out in a previous chapter.

The principal improvements and changes in machine fitting at the present time is in the application of special tools. A lathe, a planing machine, or drilling machine as a standard machine, must be adapted to a certain range of work, but it is evident that if such tools were specially arranged for either the largest or the smallest pieces that come within their capacity, more work could be performed in a given time and consequently at less expense. It is also evident that machine tools must be kept constantly at work in order to be profitable, and when there are not sufficient pieces of one kind to occupy a machine, it must be employed on various kinds of work; but whenever there are sufficient pieces of the same size upon which certain processes of a uniform character are to be performed, there is a gain by having machines constructed to conform as nearly as possible to the requirements of special work, and without reference to any other.

It is now proposed to review the standard tools of a fitting shop, noticing the general principles of their construction and especially of their operation; not by drawings nor descriptions to show what a lathe or a planing machine is, nor how some particular engineer has constructed such tools, but upon the plan explained in the introduction, presuming the reader to be familiar with the names and purposes of standard machine tools. If he has not learned this much, and does not understand the

names and general objects of the several operations carried on in a fitting shop, he should proceed to acquaint himself thus far before troubling himself with books of any kind.

(1.) Why cannot the parts of machinery be made to accurate dimensions by forging or casting?—(2.) What is the difference between hand tool and machine tool operation as to truth?—(3.) Why cannot hand-work be employed in duplicating the parts of machinery?—(4.) What is the difference between standard and special machine tools?

CHAPTER XXX.

TURNING LATHES.

In machinery the ruling form is cylindrical; in structures other than machinery, those which do not involve motion, the ruling form is rectangular.

Machine motion is mainly rotary; and as rotary motion is accomplished by cylindrical parts such as shafts, bearings, pulleys and wheels, we find that the greater share of machine tools are directed to preparing cylindrical forms. If we note the area of the turned, bored and drilled surface in ordinary machinery, and compare with the amount of planed surface, we will find the former not less than as two to one in the finer class of machinery, and as three to one in the coarser class; from this may be estimated approximately the proportion of tools required for operating on cylindrical surfaces and plane surfaces; assuming the cutting tools to have the same capacity in the two cases, the proportion will be as three to one. This difference between the number of machines required for cylindrical and plane surfaces is farther increased, when we consider that tools act continually on cylindrical surfaces and intermittently on plane surfaces.

In practice, the truth of this proposition is fully demonstrated by the excess in the number of lathes and boring tools compared with those for planing.

An engine lathe is for many reasons called the master tool in machine fitting. It is not only the leading tool so far as performing a greater share of the work; but an engine lathe as an organised machine combines, perhaps, a greater number of useful

and important functions, than any machine which has ever been devised. A lathe may be employed to turn, bore, drill, mill, or cut screws, and with a strong screw-feed may be employed to some extent for planing; what is still more strange, notwithstanding these various functions, a lathe is comparatively a simple machine without complication or perishable parts, and requires no considerable change in adapting it to the various purposes named.

For milling, drilling or boring ordinary work within its range, a lathe is by no means a makeshift tool, but performs these various operations with nearly all the advantages of machines adapted to each purpose. An ingenious workman who understands the adaptation of a modern engine lathe can make almost any kind of light machinery without other tools, except for planing, and may even perform planing when the surfaces are not too large; in this way machinery can be made at an expense not much greater than if a full equipment of different tools is employed. This of course can only be when no division of labour is required, and when one man is to perform all the several processes of turning, drilling, and so on.

The lathe as a tool for producing heliacal forms would occupy a prominent place among machine tools, if it were capable of performing no other work; the number of parts of machinery which have screw-threads is astonishing; clamping-bolts to hold parts together include a large share of the fitting on machinery of all kinds, while screws are the most common means for increasing power, changing movements and performing adjustments.

A finisher's engine lathe consists essentially of a strong inflexible shear or frame, a running spindle with from eight to sixteen changes of motion, a sliding head, or tail stock, and a sliding carriage to hold and move the tools.

For a half century past no considerable change has been made in engine lathes, at least no new principle of operation has been added, but many improvements have been made in their adaptation and capacity for special kinds of work. Improvements have been made in the facilities for changing wheels in screw cutting and feeding, by frictional starting gear for the carriages, an independent feed movement for turning, arrangements to adjust tools, cross feeding and so on, adding something, no doubt, to the efficiency of lathes; but the improvements named have been mainly directed to supplanting the skill of lathemen.

A proof of this last proposition is found in the fact that a thorough latheman will perform nearly as much work and do it as well on an old English lathe with plain screw feed, as can be performed on the more complicated lathes of modern construction; but as economy of skill is sometimes an equal or greater object than a saving of manual labour, estimates of tool capacity should be made accordingly. The main points of a lathe, such as may most readily affect its performance, are first—truth in the bearings of the running spindle which communicates a duplicate of its shape to pieces that are turned,—second, coincidence between the line of the spindle and the movement of the carriage,—third, a cross feed of the tool at a true right angle to the spindle and carriage movement,—fourth, durability of wearing surfaces, especially the spindle bearings and sliding ways. To these may be added many other points, such as the truth of feeding screws, rigidity of frames, and so on, but such requirements are obvious.

To avoid imperfection in the running spindles of lathes, or any lateral movement which might exist in the running bearings, there have been many attempts to construct lathes with still centres at both ends for the more accurate kinds of work. Such an arrangement would produce a true cylindrical rotation, but must at the same time involve mechanical complication to outweigh the object gained. It has besides been proved by practice that good fitting and good material for the bearings and spindles of lathes will insure all the accuracy which ordinary work demands.

It may be noticed that the carriages of some lathes move on what are termed V tracks which project above the top of lathe frames, and that in other lathes the carriages slide on top of the frames with a flat bearing. As these two plans of mounting lathe carriages have led to considerable discussion on the part of engineers, and as its consideration may suggest a plan of analysing other problems of a similar nature, I will notice some of the conditions existing in the two cases, calling the different arrangements by the names of flat shears and track shears.

These different plans will be considered first in reference to the effect produced upon the movement of carriages; this includes friction, endurance of wear, rigidity of tools, convenience of operating and the cost of construction. The cutting point in both turning and boring on a slide lathe is at the side of a piece, or nearly level with the lathe centres, and any movement of a carriage

and important functions, than any machine which has ever been devised. A lathe may be employed to turn, bore, drill, mill, or cut screws, and with a strong screw-feed may be employed to some extent for planing; what is still more strange, notwithstanding these various functions, a lathe is comparatively a simple machine without complication or perishable parts, and requires no considerable change in adapting it to the various purposes named.

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To avoid imperfection in the running [illegible] any lateral movement which might exist in [illegible] there have been many attempts to construct [illegible] centres at both ends for the more accurate [illegible] an arrangement would produce a true sp[illegible] must at the same time involve mechanism [illegible] outweigh the object gained. It has [illegible] tice that good fitting and [illegible] spindles of lathes will insu[illegible] demands.

It m[illegible] what a[illegible] frames, [illegible] frames [illegible] lathe c[illegible] of eng[illegible] analys[illegible] of the [illegible]

[illegible]

[illegible] extent of such [illegible] depend mainly [illegible] movement [illegible] of a carriage. [illegible] presses differ- [illegible] is arranged [illegible] vertical [illegible] is of [illegible] the second [illegible] nine-tenths [illegible] becomes an exact measure of the in- [illegible] work performed.

[illegible] movement [illegible] dependent upon the amount [illegible] power [illegible] surface [illegible] this surface is [illegible] resisted and the condi- [illegible] surfaces [illegible] that is, how kept [illegible] mainly considered, [illegible] at an angle of thirty to forty degrees downward [illegible] from [illegible] the centre of the [illegible]. To resist such [illegible] a flat top shear presents no surface at right angles to the [illegible] are all oblique, and not only this, but all [illegible] on one side of the shear only; for this [illegible] flat top shears have to be made much heavier than would be required if the sum of their cross section could be em- [illegible] to resist transverse strain. This difficulty can, however, [illegible] obviated by numerous cross girts, which will be found [illegible] frames having flat tops.

[illegible] moving on angular ways always moves steadily an[illegible] in any direction until lifted from its bear[illegible] and its lifting is easily opposed by [illegible] a flat shear is apt to have [illegible] of the freedom [illegible]

as for the carriages; this gives the advantage of firmly binding the two sides of the frame together in fastening the moving head, which in effect becomes a strong girt across the frame; the carriages also have an equal and independent hold on both sides of a shear. In following this matter thus far, it may be seen how many conditions may have to be considered in reasoning about so apparently simple a matter as the form of ways for lathe carriages; we might even go on to many more points that have not been mentioned; but what has been explained will serve to show that the matter is not one of opinion alone, and that without practical advantages, machine tool-makers will not follow the most expensive of these two modes of mounting lathe carriages.

Lathes in common use for machine fitting are screw-cutting engine lathes, lathes for turning only, double-geared, single-geared, and back-geared lathes, lathes for boring, hand-lathes, and pulley-turning lathes; also compound lathes with double heads and two tool carriages.

These various lathes, although of a widely varied construction and adapted to uses more or less dissimilar, are still the engine lathe either with some of its functions omitted to simplify and adapt it to some special work, or with some of the operative parts compounded to attain greater capacity.

In respect to lathe manipulation, which is perhaps the most difficult to learn of all shop operations, the following hints are given, which may prove of service to a learner. At the beginning the form of tools should be carefully studied; this is one of the great points in lathe work; the greatest [illegible] a thorough and [illegible] lathe [illegible] that [illegible] proper form and [illegible] of tools [illegible] adjustment [illegible] of tools [illegible] but the [illegible] is [illegible] greater [illegible] One of the [illegible]

hole be bored on a common slide lathe?—(7.) How can the angular ways of a lathe and the corresponding grooves in a carriage be planed to fit without employing gauges?—(8.) Give the number of teeth in two wheels to cut a screw of ten threads, when a leading screw is four threads per inch?

CHAPTER XXXI.

PLANING OR RECIPROCATING MACHINES.

THE term planing should properly be applied only to machines that produce planes or flat surfaces, but the technical use of the term includes all cutting performed in right lines, or by what may be called a straight movement of tools.

As no motion except rotary can be continuous, and as rotary movement of tools is almost exclusively confined to shaping cylindrical pieces, a proper distinction between machine tools which operate in straight lines, and those which operate with circular movement, will be to call them by the names of rotary and reciprocating.

It may be noticed that all machines, except milling machines, which act in straight lines and produce plane surfaces have reciprocating movement; the class includes planing, slotting and shaping machines; these, with lathes, constitute nearly the whole equipment of an ordinary fitting shop.

It is strange, considering the simplicity of construction and the very important office filled by machines for cutting on plane surfaces, that they were not sooner invented and applied in metal work. Many men yet working at finishing, can remember when all flat surfaces were chipped and filed, and that long after engine lathes had reached a state of efficiency and were generally employed, planing machines were not known. This is no doubt to be accounted for in the fact that reciprocal movement, except that produced by cranks or eccentrics, was unknown or regarded as impracticable for useful purposes until late years, and when finally applied it was thought impracticable to have such movements operate automatically. This may seem quite absurd to even an apprentice of the present time, yet such reciprocating movement, as a mechanical problem, is by no means so simple as it may at first appear.

A planing machine platen, for instance, moves at a uniform rate of speed each way, and by its own motion shifts or reverses the driving power at each extreme of the stroke. Presuming that there were no examples to be examined, an apprentice would find many easier problems to explain than how a planing machine can shift its own belts. If a platen or table disengages the power that is moving it, the platen stops; if the momentum carries it enough farther to engage or connect other mechanism to drive the platen in the opposite direction, the moment such mechanism comes into gear the platen must stop, and no movement can take place to completely engage clutches or shift belts. This is a curious problem that will be referred to again.

Reciprocating tools are divided into those wherein the cutting movement is given to the tools, as in shaping and slotting machines, and machines wherein the cutting movement is given to the material to be planed, as in a common planing machine. Very strangely we find in general practice that machine tools for both the heaviest and the lightest class of work, such as shaping, and butting, operate upon the first principle, while pieces of a medium size are generally planed by being moved in contact with stationary tools.

This problem of whether to move the material or to move the tools in planing, is an old one; both opinion and practice vary to some extent, yet practice is fast settling down into constant rules.

Judged upon theoretical grounds, and leaving out the mechanical conditions of operation, it would at once be conceded that a proper plan would be to move the lightest body; that is, if the tools and their attachments were heavier than the material to be acted upon, then the material should be moved for the cutting action, and *vice versa*. But in practice there are other conditions to be considered more important than a question of the relative weight of reciprocating parts; and it must be remembered that in solving any problem pertaining to machine action, the conditions of operation are to be considered first and have precedence over problems of strain, arrangement, or even the general principles of construction; that is, the conditions of operating must form a base from which proportions, arrangements, and so on, must be deduced. A standard planing machine, such as is employed for most kinds of work, is arranged with a running platen or carriage upon which

the material is fastened and traversed beneath the cutting tools. The uniformity of arrangement and design in machines of this kind in all countries wherever they are made, must lead to the conclusion that there are substantial reasons for employing running platens instead of giving a cutting movement to the tools.

A planing machine with a running platen occupies nearly twice as much floor space, and requires a frame at least one-third longer than if the platen were fixed and the tools performed the cutting movement. The weight which has to be traversed, including the carriage, will in nearly all cases exceed what it would be with a tool movement; so that there must exist some very strong reasons in favour of a moving platen, which I will now attempt to explain, or at least point out some of the more prominent causes which have led to the common arrangement of planing machines.

Strains caused by cutting action, in planing or other machines, fall within and are resisted by the framing; even when the tools are supported by one frame and the material by another, such frames have to be connected by means of foundations which become a constituent part of the framing in such cases.

Direct action and reaction are equal; if a force is exerted in any direction there must be an equal force acting in the opposite direction; a machine must absorb its own strains.

Keeping this in view, and referring to an ordinary planing machine with which the reader is presumed to be familiar, the focal point of the cutting strain is at the edge of the tools, and radiates from this point as from a centre to the various parts of the machine frame, and through the joints fixed and movable between the tools and the frame; to follow back from this cutting point through the mechanism to the frame proper; first starting with the tool and its supports and going to the main frame; then starting from the material to be planed, and following back in the other direction, until we reach the point where the strains are absorbed by the main frame, examining the joints which intervene in the two cases, there will appear some reasons for running carriages.

Beginning at the tool there is, first, a clamped joint between the tool and the swing block; second, a movable pivoted joint between the block and shoe piece; third, a clamped joint between

the shoe piece and the front saddle; fourth, a moving joint where the front saddle is gibed to the swing or quadrant plate; fifth, a clamp joint between the quadrant plate and the main saddle; sixth, a moving joint between the main saddle and the cross head; seventh, a clamp joint between the cross head and standards; and eighth, bolted joints between the standards and the main frame; making in all eight distinct joints between the tool and the frame proper, three moving, four clamped, and one bolted joint.

Starting again from the cutting point, and going the other way from the tool to the frame, there is, first, a clamped and stayed joint between the material and platen, next, a running joint between the platen and frame; this is all; one joint that is firm beyond any chance of movement, and a moving joint that is not held by adjustable gibs, but by gravity; a force which acts equally at all times, and is the most reliable means of maintaining a steady contact between moving parts.

Reviewing these mechanical conditions, we may at once see sufficient reasons for the platen movement of planing machines; and that it would be objectionable, if not impossible, to add a traversing or cutting action to tools already supported through the medium of eight joints. To traverse for cutting would require a moving gib joint in place of the bolted one, between the standards and main frame, leading to a complication of joints and movements quite impracticable.

These are, however, not the only reasons which have led to a running platen for planing machines, although they are the most important.

If a cutting movement were performed by the tool supports, it would necessarily follow that the larger a piece to be planed, and the greater the distance from the platen to the cutting point, the farther a tool must be from its supports; a reversal of the conditions required; because the heavier the work the greater the cutting strain will be, and the tool supports less able to withstand the strains to be resisted.

It may be assumed that the same conditions apply to the standards of a common planing machine, but the case is different; the upright framing is easily made strong enough by increasing its depth; but the strain upon running joints is as the distance from them at which a force is applied, or to employ a technical phrase, as the amount of overhang. With a moving

platen the larger and heavier a piece to be planed, the more firmly a platen is held down; and as the cross section of pieces usually increases with their depth, the result is that a planing machine properly constructed will act nearly as well on thick as thin pieces.

The lifting strain at the front end of a platen is of course increased as the height at which the cutting is done above its top, but this has not in practice been found a difficulty of any importance, and has not even required extra length or weight of platens beyond what is demanded to receive pieces to be planed and to resist flexion in fastening heavy work. The reversing movement of planing machine platens already alluded to is one of the most complex problems in machine tool movement.

Platens as a rule run back at twice the forward or cutting movement, and as the motion is uniform throughout each stroke, it requires to be stopped at the extremes by meeting some elastic or yielding resistance which, to use a steam phrase, "cushions" or absorbs the momentum, and starts the platen back for the return stroke.

This object is attained in planing machines by the friction of the belts, which not only cushions the platen like a spring, but in being shifted opposes a gradually increasing resistance until the momentum is overcome and the motion reversed. By multiplying the movement of the platen with levers or other mechanism, and by reason of the movement that is attained by momentum after the driving power ceases to act, it is found practicable to have a platen 'shift its own belts,' a result that would never have been reached by theoretical deductions, and was no doubt discovered by experiment, like the automatic movement of engine valves is said to have been.

It is not intended to claim that this platen-reversing motion cannot, like any other mechanical movement, be resolved mathematically, but that the mechanical conditions are so obscure and the invention made at a time that warrants the supposition of accidental discovery.

In the driving gearing of planing machines, conditions which favour the reversing movement are high speed and narrow driving belts. The time in which belts may be shifted is as their speed and width; to be shifted a belt must be deflected or bent edgewise, and from this cause wind spirally in order to pass from one pulley to another. To bend or deflect a belt edge-

wise there will be required a force in proportion to its width, and the time of passing from one pulley to another is as the number of revolutions made by the pulleys.

Planing machines of the most improved construction are driven by two belts instead of one, and many mechanical expedients have been adopted to move the belts differentially, so that both should not be on the driving pulley at the same time, but move one before the other in alternate order. This is easily attained by simply arranging the two belts with the distance between them equal to one and one-half or one and three-fourth times the width of the driving pulley. The effect is the same as that accomplished by differential shifting gearing, with the advantage of permitting an adjustment of the relative movement of the belts.

Another principle in planing machines which deserves notice is the manner of driving carriages or platens; this is usually performed by means of spur wheels and a rack. A rack movement is smooth enough, and effective enough so far as a mechanical connection between the driving gearing and a platen, but there is a difficulty met with from the torsion and elasticity of cross-shafts and a train of reducing gearing. In all other machines for metal cutting, it has been a studied object to have the supports for both the tools and the material as rigid as possible; but in the common type of planing machines, such as have rack and pinion movement, there is a controversion of this principle, inasmuch as a train of wheels and several cross-shafts constitute a very effective spring between the driving power and the point of cutting, a matter that is easily proved by planing across the teeth of a rack, or the threads of a screw, on a machine arranged with spur wheels and the ordinary reducing gearing. It is true the inertia of a platen is interposed and in a measure overcomes this elasticity, but in no degree that amounts to a remedy.

A planing machine invented by Mr Bodmer in 1841, and since improved by Mr William Sellers of Philadelphia, is free from this elastic action of the platen, which is moved by a tangent wheel or screw pinion. In Bodmer's machine the shaft carrying the pinion was parallel to the platen, but in Sellers' machine is set on a shaft with its axis diagonal to the line of the platen movement, so that the teeth or threads of the pinion act partly by a screw motion, and partly by a progressive forward movement

[illegible] the teeth of wheels. The rack on the planer of Mr Sellers' machine is arranged with its teeth at a proper angle to balance the friction arising from the rubbing action of the pinion, which angle has been demonstrated as correct at 5°, the ordinary coefficient of friction; as the pinion-shaft is strongly supported on each side of the pinion, and the thrust of the cutting force [illegible] in the line of the pinion shaft, there is but little if any elasticity, so that the motion is positive and smooth.

[illegible] of these machines is alluded to here mainly for the purpose of calling attention to what constitutes a new and [illegible] mechanical movement, one that will furnish a most [illegible] and deserves a more extended application in [illegible] motion.

[illegible] be employed directly to shift the belts of a [illegible] planing machines generally con- [illegible] running tools?—(3. What [illegible] wheels to drive a planing [illegible] shifting the belts of a plan- [illegible] the screeching of belts [illegible] What conditions favour the [illegible]

[illegible] differ from [illegible] may be [illegible] rigidly [illegible] machines. The [illegible] form of [illegible] shaving, [illegible] and not [illegible] difference [illegible] movement is [illegible] the material. [illegible] angles to [illegible] of gravity,

and not parallel to the face of the table, as in planing and shaping machines.

The feed motion in slotting machines, because of the tools being held rigidly, has to operate differently from that of planing machines. The cross-feed of a planing machine may act during the return stroke, but in slotting machines, the feed movement should take place at the end of the up-stroke, or after the tools are clear of the material; so much of the stroke as is made during the feeding action is therefore lost; and because of this, mechanism for operating the feed usually has a quick abrupt action so as to save useless movement of the cutter bar.

The relation between the feeding and cutting motion of reciprocating machines is not generally considered, and forms an interesting problem for investigation.

(1.) Name some of the differences between planing and slotting machines.—(2.) Why should the feed motion of a slotting machine act abruptly?—(3.) To what class of work are slotting machines especially adapted?

CHAPTER XXXIII.

SHAPING MACHINES.

SHAPING machines as machine tools occupy a middle place between planing and slotting machines; their movements correspond more to those of slotting machines, while the operation of the tools is the same as in planing. Some of the advantages of shaping over planing machines for certain kinds of work are, because of the greater facilities afforded for presenting and holding small pieces, or those of irregular shape; the supports or tables having both vertical and horizontal faces to which pieces may be fastened, and the convenience of the mechanism for adjusting and feeding tools.

Shaping machines are generally provided with adjustable vices, devices for planing circular forms, and other details which cannot be so conveniently employed with planing machines. Another feature of shaping machines is a positive range of the cutting stroke produced by crank motion, which permits tools to

be stopped with precision at any point; this admits of planing slots, keyways, and such work as cannot well be performed upon common planing machines.

Shaping machines are divided into two classes, one modification with a lateral feed of the tools and cutter bar, technically called "travelling head machines," the other class with a feed motion of the table which supports the work, called table-feeding machines. The first modification is adapted for long pieces to be planed transversely, such as toothed racks, connecting rods, and similar work; the second class to shorter pieces where much hand adjustment is required.

An interesting study in connection with modern shaping machines is the principle of various devices called 'quick return' movements. Such devices consist of various modifications of slotted levers, and what is known as Whitworth's quick return motion.

The intricacy of the subject renders it a difficult one to deal with except by the aid of diagrams, and as such mechanism may be inspected in almost any machine fitting shop, attention is called to the subject as one of the best that can be chosen for demonstration by diagrams. Problems of these variable speed movements are not only of great interest, but have a practical importance not found in many better known problems which take up time uselessly and have no application in a practical way.

The remarks, given in a former place, relating to tools for turning, apply to those for planing as well, except that in planing tools greater rigidity and strength are required.

(1.) Why are shaping machines better adapted than planing machines for planing slots, key-ways, and so on? — (2.) What objects are gained by a quick return motion of the cutter bar of shaping machines?

CHAPTER XXXIV.

BORING AND DRILLING.

Boring, as distinguished from drilling, consists in turning out annular holes to true dimensions, while the term drilling is applied to perforating or sinking holes in solid material. In

boring, tools are guided by axial support independent of the bearing of their edges on the material, while in drilling, the cutting edges are guided and supported mainly from their contact with and bearing on the material drilled.

Owing to this difference in the manner of guiding and supporting the cutting edges, and the advantages of an axial support for tools in boring, it becomes an operation by which the most accurate dimensions are attainable, while drilling is a comparatively imperfect operation; yet the ordinary conditions of machine fitting are such that nearly all small holes can be drilled with sufficient accuracy.

Boring may be called internal turning, differing from external turning, because of the tools performing the cutting movement, and in the cut being made on concave instead of convex surfaces; otherwise there is a close analogy between the operations of turning and boring. Boring is to some extent performed on lathes, either with boring bars or by what is termed chuck-boring, in the latter the material is revolved and the tools are stationary.

Boring may be divided into three operations as follows: chuck-boring on lathes; bar-boring, when a boring bar runs on points or centres, and is supported at the ends only; and bar-boring when a bar is supported in and fed through fixed bearings. The principles are different in these operations, each one being applicable to certain kinds of work. A workman who can distinguish between these plans of boring, and can always determine from the nature of a certain work which is the best to adopt, has acquired considerable knowledge of fitting operations.

Chuck-boring is employed in three cases; for holes of shallow depth, taper holes, and holes that are screw-threaded. As pieces are overhung in lathe-boring there is not sufficient rigidity neither of the lathe spindle nor of the tools to admit of deep boring. The tools being guided in a straight line, and capable of acting at any angle to the axis of rotation, the facilities for making tapered holes are complete; and as the tools are stationary, and may be instantly adjusted, the same conditions answer for cutting internal screw-threads; an operation corresponding to cutting external screws, except that the cross motions of the tool slide are reversed.

The second plan of boring by means of a bar mounted on points or centres is one by which the greatest accuracy is

attainable: it is like chuck-boring a lathe operation, and one for which no better machine than a lathe has been devised, at least for the smaller kinds of work. It is a problem whether in ordinary machine fitting there is not a gain by performing all boring in this manner whenever the rigidity of boring bars is sufficient without auxiliary supports, and when the bars can pass through the work. Machines arranged for this kind of boring can be employed in turning or boring as occasion may require.

When a tool is guided by turning on points, the movement is perfect, and the straightness or parallelism of holes bored in this manner is dependent only on the truth of the carriage movement. This plan of boring is employed for small steam cylinders, cylindrical valve seats, and in cases where accuracy is essential.

The third plan of boring with bars resting in bearings is more extensively practised, and has the largest range of adaptation. A feature of this plan of boring is that the form of the boring-bar, or any imperfection in its bearings, is communicated to the work; a want of straightness in the bar makes tapering holes. This, of course, applies to cases where a bar is fed through fixed bearings placed at one or both ends of a hole to be bored. If a boring-bar is bent, or out of truth between its bearings, the diameter of the hole being governed by the extreme sweep of the cutters is untrue to the same extent, because as the cutters move along and come nearer to the bearings, the bar runs with more truth, forming a tapering hole diminishing toward the rests or bearings. The same rule applies to some extent in chuck-boring, the form of the lathe spindle being communicated to holes bored; but lathe spindles are presumed to be quite perfect compared with boring bars.

The prevailing custom of casting machine frames in one piece, or in as few pieces as possible, leads to a great deal of bar-boring, most of which can be performed accurately enough by boring bars supported in and fed through bearings. By setting up temporary bearings to support boring-bars, and improvising means of driving and feeding, most of the boring on machine frames can be performed on floors or sole plates and independent of boring machines and lathes. There are but few cases in which the importance of studying the principles of tool action is more clearly demonstrated than in this matter of boring; even long practical

experience seldom leads to a thorough understanding of the various problems which it involves.

Drilling differs in principle from almost every other operation in metal cutting. The tools, instead of being held and directed by guides or spindles, are supported mainly by the bearing of the cutting edges against the material.

A common angular-pointed drill is capable of withstanding a greater amount of strain upon its edges, and rougher use than any other cutting implement employed in machine fitting. The rigid support which the edges receive, and the tendency to press them to the centre, instead of to tear them away as with other tools, allows drills to be used when they are imperfectly shaped, improperly tempered, and even when the cutting edges are of unequal length.

Most of the difficulties which formerly pertained to drilling are now removed by machine-made drills which are manufactured and sold as an article of trade. Such drills do not require dressing and tempering or fitting to size after they are in use, make true holes, are more rigid than common solid shank drills, and will drill to a considerable depth without clogging.

A drilling machine, adapted to the usual requirements of a machine fitting establishment, consists essentially of a spindle arranged to be driven at various speeds, with a movement for feeding the drills; a firm table set at right angles to the spindle, and arranged with a vertical adjustment to or from the spindle, and a compound adjustment in a horizontal plane. The simplicity of the mechanism required to operate drilling tools is such that it has permitted various modifications, such as column drills, radial drills, suspended drills, horizontal drills, bracket drills, multiple drills, and others.

Drilling, more than any other operation in metal cutting, requires the sense of feeling, and is farther from such conditions as admit of power feeding. The speed at which a drill may cut without heating or breaking is dependent upon the manner in which it is ground and the nature of the material drilled, the working conditions may change at any moment as the drilling progresses; so that hand feed is most suitable. Drilling machines arranged with power feed for boring should have some means of permanently disengaging the feeding mechanism to prevent its use in ordinary drilling.

I am well aware how far this opinion is at variance with prac-

tice, especially in England ; yet careful observation in a workshop will prove that power feed in ordinary drilling effects no saving of time or expense.

(1.) What is the difference between boring and drilling ?—(2.) Why will drills endure more severe use than other tools ?—(3.) Why is hand feeding best suited for drills ?—(4.) What is the difference between boring with a bar supported on centres and one fed through journal bearings ?

CHAPTER XXXV.

MILLING.

MILLING relates to metal cutting with serrated rotary cutters, and differs in many respects from either planing or turning. The movement of the cutting edges can be more rapid than with tools which act continuously, because the edges are cooled during the intervals between each cut ; that is, if a milling tool has twenty teeth, any single tooth or edge acts only from a fifteenth to a twentieth part of the time ; and as the cutting distance or time of cutting is rarely long enough to generate much heat, the speed of such tools may be one-half greater than for turning, drilling, or planing tools. Another distinction between milling and other tools is the perfect and rigid manner in which the cutting edges are supported ; they are short and blunt, besides being usually carried on short rigid mandrils. A result of this rigid support of the tools is seen in the length of the cutting edges that can be employed, which are sometimes four inches or more in length. It is true the amount of material cut away in milling is much less than the edge movement will indicate when compared with turning or planing ; yet the displacing capacity of a milling machine exceeds that of either a lathe or a planing machine. Theoretically the cutting or displacing capacity of any metal or wood cutting machine, is as the length of the edges multiplied into the speed of their cutting movement ; a rule which applies very uniformly in wood cutting, and also in metal cutting within certain limits ; but the strains that arise in metal cutting are so great that they may exceed all means of resisting them either in the material acted upon, or in the means of supporting tools, so that the length

cutting edges is limited. In turning chilled rolls at Pittsburg, ols to six inches wide are employed, and the effect produced is the length of the edge; but the depth of the cut is slight, and e operation is only possible because of the extreme rigidity of e pieces turned, and the tools being supported without movable ints as in common lathes.

Under certain conditions a given quantity of soft iron or steel ay be cut away at less expense, and with greater accuracy, by illing than by any other process.

A milling tool with twenty edges should represent as much earing capacity as a like number of separate tools, and may e said to equal twenty duplicate tools; hence, in cutting grooves, otches, or similar work, a milling tool is equivalent to a large umber of duplicate single tools, which cannot be made or set ith the same truth; so that milling secures accuracy and duplica- on, objects which are in many cases more important than speed.

Milling, as explained, being a more rapid process than either laning or turning, it seems strange that so few machines of this ind are employed in engineering shops. This points to some ifficulty to be contended with in milling, which is not altogether pparent, because economic reasons would long ago have led to a ore extended use of milling processes, if the results were as rofitable as the speed of cutting indicates. This is, however, ot the case, except on certain kinds of material, and only for ertain kinds of work.

The advantages gained by milling, as stated, are speed, uplication, and accuracy; the disadvantages are the expense of reparing tools and their perishability.

A solid milling cutter must be an accurately finished piece of ork, made with more precision than can be expected in the ork it is to perform. This accuracy cannot be attained by rdinary processes, because such tools, when tempered, are liable become distorted in shape, and frequently break. When ardened they must be finished by grinding processes, if intended r any accurate work; in fact, no tools, except gauging imple- ents, involve more expense to prepare, and none are so liable accident when in use.

Such tools consist of a combination of cutting edges, all of hich may be said to depend on each one; because if one breaks, e next in order will have a double duty to perform, and will

soon follow—a reversal of the old adage, that 'union is strength,' if by strength is meant endurance.

In planing and turning, the tools require no exact form; they can be roughly made, except the edge, and even this, in most cases, is shaped by the eye. Such tools are maintained at a trifling expense, and the destruction of an edge is a matter of no consequence. The form, temper, and strength can be continually adapted to the varying conditions of the work and the hardness of material. The line of division between planing and milling is fixed by two circumstances—the hardness and uniformity of the material to be cut, and the importance of duplication. Brass, clean iron, soft steel, or any homogeneous metal not hard enough to cause risk to the tools, can be milled at less expense than planed, provided there is enough work of a uniform character to justify the expense of milling tools. Cutting the teeth of wheels is an example where milling is profitable, but not to the extent generally supposed. In the manufacture of small arms, sewing machines, clocks, and especially watches, where there is a constant and exact duplication of parts, milling is indispensable. Such manufactures are in some cases founded on milling operations, as will be pointed out in another chapter.

Milling tools large enough to admit of detachable cutters being employed, are not so expensive to maintain as solid tools. Edge movement can sometimes be multiplied in this way, so as to greatly exceed what a single tool will perform.

Milling tools are employed at Crewe for roughing out the slots in locomotive crank axles. A number of detachable tools are mounted on a strong disc, so that four to six will act at one time; in this way the displacement exceeds what a lathe can perform when acting continuously with two tools. Rotary planing machines constructed on the milling principle, have been tried for plane surfaces, but with indifferent success, except for rough work.

There is nothing in the construction or operation of milling machines but what will be at once understood by a learner who sees them in operation. The whole intricacy of the process lies in its application or economic value, and but very few, even among the most skilled, are able in all cases to decide when milling can be employed to advantage. Theoretical conclusions, aside from practical experience, will lead one to suppose that

illing can be applied in nearly all kinds of work, an opinion which has in many cases led to serious mistakes.

(1.) If milling tools operate faster than planing or turning tools, why e they not more employed?—(2.) How may the effect produced by tting tools generally be computed?—(3.) To what class of work are illing machines especially suited?—(4.) Why do milling processes oduce more accurate dimensions than are attainable by turning or aning?—(5.) Why can some branches of manufacture be said to pend on milling processes?

CHAPTER XXXVI.

SCREW-CUTTING.

HE tools employed for cutting screw threads constitute a separa te class among the implements of a fitting shop, and it is nsidered best to notice them separately.

Screw-cutting is divided into two kinds, one where the blanks pieces to be threaded are supported on centres, the tools held d guided independently of their bearing at the cutting edges, lled chasing; the other process is where the blanks have no ial support, and are guided only by dies or cutting tools, called e-cutting.

The first of these operations includes all threading processes rformed on lathes, whether with a single tool, by dies carried sitively by slide rests, or by milling.

The second includes what is called threading in America and rewing in England. Machines for this purpose consist sentially of mechanism to rotate either the blank to be cut or e dies, and devices for holding and presenting the blanks.

Chasing produces screws true with respect to their axis, and is e common process of threading all screws which are to have a nning motion in use, either of the screw itself, or the nut.

Die-cutting produces screws which may not be true, but are ll sufficiently accurate for most uses, such as clamping and ning together the parts of machinery or other work.

Chasing operations being lathe work, and involving no inciples not already noticed, what is said further will be in ference to die-cutting or bolt-threading machines, which,

simple as they may appear to the unskilled, involve, nevertheless many intricacies which will not appear upon superficial examination.

Screw-cutting machines may be divided into modifications as follows :—(1) Machines with running dies mounted in what is called the head; (2) Machines with fixed dies, in which motion is given to the rod or blank to be threaded; (3) Machines with expanding dies which open and release the screws when finished without running back; (4) Machines with solid dies, in which the screws have to be withdrawn by changing the motion of the driving gearing; making in all four different types.

If these various plans of arranging screw-cutting machines had reference to different kinds of work, it might be assumed that all of them are correct, but they are as a rule all applied to the same kind of work; hence it is safe to conclude that there is one arrangement better than the rest, or that one plan is right and the others wrong. This matter may in some degree be determined by following through the conditions of use and application.

Between a running motion of the dies, or a running motion of the blanks, there are the following points which may be noticed.

If dies are fixed, the clamping mechanism to hold the rods has to run with the spindle; such machines must be stopped while fastening the rods or blanks. Clamping jaws are usually as little suited for rotation on a spindle as dies are, and generally afford more chances for obstruction and accident. To rotate the rods, if they are long, they must pass through the driving spindle, because machines cannot well be made of sufficient length to receive long rods. In machines of this class, the dies have to be opened and closed by hand instead of by the driving power, which can be employed for the purpose when the dies are mounted in a running head.

With running dies, blanks may be clamped when a machine is in motion, and as the blank does not revolve, it may, when long, be supported in any temporary manner. The dies can be opened and closed by the driving power also, and no stopping of a machine is necessary; so that several advantages of considerable importance may be gained by mounting the dies in a running head, a plan which has been generally adopted in late years by machine tool makers both in England and America.

In respect to the difference between expanding and solid dies it consists mainly in the time required to run back, and the

injury to dies which this operation occasions. Uniformity of size is within certain limits insured by solid dies, but they are more liable to derangement and less easy to repair than expanding or independent dies.

Another difference between solid and expanding dies, which may be pointed out, is in the firmness with which the cutting edges are held. With a solid die, the edges or teeth being all combined in one solid piece, are firmly held in a fixed position; while with expanding dies their position has to be maintained by mechanical devices which are liable to yield under the pressure which arises in cutting. The result is, that the precision with which a screwing machine with movable dies will act, is dependent upon the strength of the 'abutment' behind the dies, which should be a hard unyielding surface with as much area as possible.

Connected with screw dies, there are various problems, such as clearance behind the cutting edge; whether an odd or even number of edges are best; how many threads require to be bevelled at the starting point; and many other matters about which there are no determined rules. The diversity of opinion that will be met with on these points, and in reference to taps, the form of screw-threads, and so on, will convince a learner of the intricacies in this apparently simple matter of cutting screw-threads.

(1.) Describe the different modifications of screw-cutting machines. —(2.) What is gained by revolving the dies instead of the rods?—(3.) What is gained by expanding dies?—(4.) What is the difference between sorews cut by chasing and those cut on a screw-cutting machine?

CHAPTER XXXVII.

STANDARD MEASURES.

MACHINES are composed of parts connected together by rigid and movable joints; rigid joints are necessary because of the expense, and in most cases the impossibility, of constructing framing and other fixed detail in one piece.

All moving parts must of course be independent of fixed parts, the relation between the two being maintained by what has been called running joints.

It is evident that when the parts of a machine are joined together, each piece which has contact on more than one side must have specific dimensions; it is farther evident that as many of the joints in a machine as are to accommodate the exigencies of construction must be without space, that is, they represent continued sections of what should be solid material, if it were possible to construct the parts in that manner. This also demands specific dimensions.

In arranging the details of machines, it is impossible to have a special standard of dimensions for each case, or even for each shop; the dimensions employed are therefore made to conform to some general standard, which by custom becomes known and familiar to workmen and to a country, or as we may now say to all countries.

A standard of lineal measures, however, cannot be taken from one country to another, or even transferred from one shop to another without the risk of variation; and it is therefore necessary that such a standard be based upon something in nature to which reference can be made in cases of doubt.

In ages past, various attempts were made to find some constant in nature on which measures could be based. Some of these attempts were ludicrous, and all of them failures, until the vibrations of a pendulum connected length and space with time. The problem was then more easy. The changes of seasons and the movement of heavenly bodies had established measures of time, so that days, hours, and minutes became constants, proved and maintained by the unerring laws of nature.

A pendulum vibrating in uniform time regardless of distance, but always as its length, if arranged to perform one vibration in a given time, gave a constant measure of length. Thus lineal measure comes from time; cubic or solid measures from lineal measure, and standards of weight from the same source; because when a certain quantity of a substance of any kind could be determined by lineal measurement, and this quantity was weighed, a standard of weight would be reached, provided there was some substance sufficiently uniform, to which reference could be made in different countries. Such a substance is sea or pure water; weighed in vacuo, or with the air at an assumed

density, water gives a result constant enough for a standard of weight.

It is a strange thought that with all the order, system, and regularity, existing in nature, there is nothing but the movements of the heavenly bodies constant enough to form a base for gauging tests. The French standard based upon the calculated length of the meridian may be traced to this source.

Nothing animate or inanimate in nature is uniform; plants, treés, animals, are all different; even the air we breathe and the temperature around us is constantly changing; only one thing is constant, that is time, and to this must we go for all our standards.

I am not aware that the derivation of our standard measures has been, in an historical way, as the foregoing remarks will indicate, nor is it the purpose here to follow such history. A reader, whose attention is directed to the subject, will find no trouble in tracing the matter from other sources. The present object is to show what a wonderful series of connections can be traced from so simple a tool as a measuring gauge, and how abstruse, in fact, are many apparently simple things, often regarded as not worth a thought beyond their practical application.

(1.) Why are machine frames constructed in sections, instead of being in one piece?—(2.) Why must parts which have contact on opposite sides have specific dimensions?—(3.) What are standards of measure based upon in England, America, and France?—(4.) How can weight be measured by time?—(5.) Has the French metre proved a standard admitting of test reference?

CHAPTER XXXVIII.

GAUGING IMPLEMENTS.

Among the improvements in machine fitting which have in recent years come into general use, is the employment of standard gauges, by means of which uniform dimensions are maintained, and within certain limits, an interchange of the parts of machinery is rendered possible.

Standard gauging implements were introduced about the year

1840, by the celebrated Swiss engineer, John G. Bodmer, a man who for many reasons deserves to be considered as the founder of machine tool manufacture. He not only employed gauges in his works to secure duplicate dimensions, but also invented and put in use many other reforms in manipulation; among these may be mentioned the decimal or metrical division of measures, a system of detail drawings classified by symbols, the mode of calculating wheels by diametric pitch, with many other things which characterise the best modern practice.

The importance of standard dimensions, and the effect which a system of gauging may have in the construction of machines, will be a matter of some difficulty for a learner to understand. The interchangeability of parts, which is the immediate object in employing gauges, is plain enough, and some of the advantages at once apparent, yet the ultimate effects of such a system extend much farther than will at first be supposed.

The division of labour, that system upon which we may say our great industrial interests are founded, is in machine fitting promoted in a wonderful degree by the use of gauging implements. If standard dimensions can be maintained, it is easy to see that the parts of a machine can be constructed by different workmen, or in different shops, and these parts when assembled all fit together, without that tedious and uncertain plan of try-fitting which was once generally practised. There are, it is true, certain kinds of fitting which cannot well be performed by gauges; moving flat surfaces, such as the bearings of lathe slides or the faces of steam engine valves, are sooner and better fitted by trying them together and scraping off the points of contact; but even in such cases the character of the work will be improved, if one or both surfaces have been first levelled by gauging or surface plates.

In cylindrical fitting, which as before pointed out, constitutes the greater part in machine fitting, gauges are especially important, because trial-fitting is in most cases impossible.

Flat or plane joints nearly always admit of adjustment between the fitted surfaces; that is, the material scraped or ground away in fitting can be compensated by bringing the pieces nearer together; but parallel cylindrical joints cannot even be tried together until finished, consequently, there can be nothing cut away in trying them together. Tapering, or conical joints, can of course be trial-fitted, and even parallel fits are sometimes

made by trial, but it is evident that the only material that can be cut away in such cases, is what makes the difference between a fit too close, and one which will answer in practice.

As to the practical results which may be attained by a gauging system, it may be said that they are far in advance of what is popularly supposed, especially in Europe, where gauges were first employed.

The process of milling, which has been so extensively adopted in the manufacture of guns, watches, sewing-machines, and similar work in America, has, on principles explained in the chapter on milling, enabled a system of gauging which it is difficult to comprehend without seeing the processes carried on. And so important is the effect due to this duplicating or gauging system, that several important branches of manufacture have been controlled in this way, when other elements of production, such as the price of labour, rent, interest, and so on, have been greatly in favour of countries where the trying system is practised.

As remarked, the gauging system is particularly adapted to, or enabled by milling processes, and of course must have its greatest effect in branches of work directed to the production of uniform articles, such as clocks, watches, sewing-machines, guns, hand tools, and so on. That is, the direct effect on the cost of processes will be more apparent and easily understood in such branches of manufacture; yet in general engineering work, where each machine is more or less modified, and made to special plans, the commercial gain resulting from the use of gauges is considerable.

In respect to repairing alone, the consideration of having the parts of machinery fitted to standard sizes is often equal to its whole value.

Machinery subjected to destructive wear, and to be operated at a distance from machine shops—locomotive engines for example—if not constructed with standard dimensions, may, by the detention due to repairing, cause a loss and inconvenience equal to their value; if a shaft wheel bearing, or even a fitted screw bolt is broken, time must be allowed to make the parts new; and in order to fit them, the whole machine, or such of its details as have connection with the broken parts, must be taken to a shop in order to fit by trial.

The duplicate system has gradually made its way in loco-

motive engineering, and will no doubt extend to the whole of railway equipment, as constants for dimensions are proved and agreed upon.

The gauging system has been no little retarded by a selfish and mistaken opinion that an engineering establishment may maintain peculiar standards of its own; in fact, relics of this spirit are yet to be met with in old machines, where the pitch of screw-threads has been made to fractional parts of an inch, so that engineers, other than the original makers, could not well perform repairing, or replace broken parts.

One of the effects of employing gauges in machine fitting is to inspire confidence in workmen. Instead of a fit being regarded as a mysterious result more the work of chance than design, men accustomed to gauges come to regard precision as something both attainable and indispensable. A learner, after examining a set of well fitted cylindrical gauges, will form a new conception of what a fit is, and will afterwards have a new standard fixed in his mind.

The variation of dimensions which are sensible to the touch at one ten-thousandth part of an inch, furnishes an example of how important the human senses are even after the utmost precision attainable by machine action. Pieces may pass beneath the cutters of a milling machine under conditions, which so far as machinery avails will produce uniform sizes, yet there is no assurance of the result until the work is felt by gauges.

The eye fails to detect variations in size, even by comparison, long before we reach the necessary precision in common fitting. Even by comparison with figured scales or measuring with rules, the difference between a proper and a spoiled fit is not discernible by sight.

Many of the most accurate measurements are, however, performed by sight, with vernier calipers for example, the variation being multiplied hundreds or thousands of times by mechanism, until the least differences can be readily seen.

In multiplying the variations of a measuring implement by mechanism, it is obvious that movable joints must be employed; it is also obvious that no positive joint, whether cylindrical or flat, could be so accurately fitted as to transmit such slight movement as occurs in gauging or measuring. This difficulty is in most measuring instruments overcome by employing a principle not

before alluded to, but common in many machines, that of elastic compensation.

A pair of spring calipers will illustrate this principle. The points are always steady, because the spring acting continually in one direction compensates the loose play that may be in the screw. In a train of tooth wheels there is always more or less play between the teeth; and unless the wheels always revolve in one direction, and have some constant resistance offered to their motion, 'backlash' or irregular movement will take place; but if there is some constant and uniform resistance such as a spring would impart, a train of wheels will transmit the slightest motion throughout.

The extreme nicety with which gauging implements are fitted seems at first thought to be unnecessary, but it must be remembered that a cylindrical joint in ordinary machine fitting involves a precision almost beyond the sense of feeling, and that any sensible variation in turning gauges is enough to spoil a fit.

Opposed to the maintenance of standard dimensions are the variations in size due to temperature. This difficulty applies alike to gauging implements and to parts that are to be tested; yet in this, as in nearly every phenomenon connected with matter, we have succeeded in turning it to some useful purpose. Bands of iron, such as the tires of wheels when heated, can be 'shrunk' on, and a compressive force and security attained, which would be impossible by forcing the parts together both at the same temperature. Shrinking has, however, been almost entirely abandoned for such joints as can be accurately fitted.

(1.) How may gauging implements affect the division of labour?—(2.) In what way does standard dimensions affect the value of machinery?—(3.) Why cannot cylindrical joints be fitted by trying them together?—(4.) Under what circumstances is it most important that the parts of machinery should have standard dimensions?—(5.) Which sense is most acute in testing accurate dimensions?—(6.) How may slight variations in dimensions be made apparent to sight?

CHAPTER XXXIX.

DESIGNING MACHINES.

It will scarcely be expected that any part of the present work, intended mainly for apprentice engineers, should relate to designing machines, yet there is no reason why the subject should not to some extent be treated of; it is one sure to engage more or less attention from learners, and the study of designing machines, if properly directed, cannot fail to be of advantage.

There is, perhaps, no one who has achieved a successful experience as an engineer but will acknowledge the advantages derived from early efforts to generate original designs, and none who will not admit that if their first efforts had been more carefully directed, the advantages gained would have been greater.

It is exceedingly difficult for an apprentice engineer, without experimental knowledge, to choose plans for his own education, or to determine the best way of pursuing such plans when they have been chosen; and there is nothing that consumes so much time, or is more useless than attempting to make original designs, if there is not some systematic method followed.

There is but little object in preparing designs, when their counterparts may already exist, so that in making original plans, there should be a careful research as to what has been already done in the same line. It is not only discouraging, but annoying, after studying a design with great care, to find that it has been anticipated, and that the scheme studied out has been one of reproduction only. For this reason, attempts to design should at first be confined to familiar subjects, instead of venturing upon unexplored ground.

Designing is in many respects the same thing as invention, except that it deals more with mechanism than principles, although it may, and often does include both. Like invention, designing should always be attempted for the attainment of some definite object laid down at the beginning, and followed persistently throughout.

It is not always an easy matter to hit upon an object to which designs may be directed; and although at first thought it may seem that any machine, or part of a machine, is capable of im-

provement, it will be found no easy matter to detect existing faults or to conceive plans for their remedy.

A new design should be based upon one of two suppositions—either that existing mechanism is imperfect in its construction, or that it lacks functions which a new design may supply; and if those who spend their time in making plans for novel machinery would stop to consider this from the beginning, it would save no little of the time wasted in what may be called scheming without a purpose.

After determining the ultimate objects of an improvement, and laying down the general principles which should be followed in the preparation of a design, there is nothing connected with constructive engineering that can be more nearly brought within general rules than arranging details. I am well aware of how far this statement is at variance with popular opinion among mechanics, and of the very thorough knowledge of machine application and machine operation required in making designs, and mean that there are certain principles and rules which may determine the arrangement and distribution of material, the position and relation of moving parts, bearings, and so on, and that a machine may be built up with no more risk of mistakes than in erecting a permanent structure.

Designing machines must have reference to adaptation, endurance, and the expense of construction. Adaptation includes the performance of machinery, its commercial value, or what the machinery may earn in operating; endurance, the time that machines may operate without being repaired, and the constancy of their performance; expense, the investment represented in machinery.

The adaptation, endurance, and cost of machines in designing become resolved into problems of movements, the arrangement of parts, and proportions.

Movements and strains may be called two of the leading conditions upon which designs for machines are based: movements determine general dimensions, and strains determine the proportions and sizes of particular parts. Movement and strain together determine the nature and area of bearings or bearing surfaces.

The range and speed of movement of the parts of machines are elements in designing that admit of a definite determination from the work to be accomplished, but arrangement cannot be so

determined, and is the most difficult to find data for. To sum up these propositions we have:—

1. A conception of certain functions in a machine, and some definite object which it is to accomplish.

2. Plans of adaptation and arrangement of the component parts of the machinery, or organisation as it may be called.

3. A knowledge of specific conditions, such as strains, the range and rate of movements, and so on.

4. Proportions of the various parts, including the framing, bearing surfaces, shafts, belts, gearing, and other details.

5. Symmetry of appearance, which is often more the result of obvious adaptation than ornamentation.

To illustrate the practical application of what has preceded, let it be supposed, for example, that a machine is to be made for cutting teeth in iron racks ¾ in. pitch and 3 in. face, and that a design is to be prepared without reference to such machines as may already be in use for the purpose.

It is not assumed that an actual design can be made which by words alone will convey a comprehensive idea of an organised machine; it is intended to map out a course which will illustrate a plan of reasoning most likely to attain a successful result in such cases.

The reader, in order to better understand what is said, may keep in mind a common shaping machine with crank motion, a machine which nearly fills the requirements for cutting tooth racks.

Having assumed a certain work to do, the cutting of tooth racks ¾ in. pitch, and 3 in. face, the first thing to be considered will be, is the machine to be a special one, or one of general adaptation? This question has to do, first, with the functions of the machine in the way of adapting it to the cutting of racks of various sizes, or to performing other kinds of work, and secondly, as to the completeness of the machine; for if it were to be a standard one, instead of being adapted only to a special purpose, there are many expensive additions to be supplied which can be omitted in a special machine. It will be assumed in the present case that a special machine is to be constructed for a particular duty only.

The work to be performed consists in cutting away the metal between the teeth of a rack, leaving a perfect outline for the teeth; and as the shape of teeth cannot well be obtained by an adjustment of tools, it must be accomplished by the shape of the tools.

The shape of the tools must, therefore, be constantly maintained, and as the cross section of the displaced metal is not too great, it may be assumed that the shape of the tools should be a profile of the whole space between two teeth, and such a space be cut away at one setting or one operation. By the application of certain rules laid down in a former place in reference to cutting various kinds of material, reciprocating or planing tools may be chosen instead of rotary or milling tools.

Movements come next in order, and consist of a reciprocating cutting movement of the tools or material, a feed movement to regulate the cutting action, and a longitudinal movement of the rack, graduated to pitch or space, the distance between the teeth.

The reciprocating cutting movement being but four inches or less, a crank is obviously the best means to produce this motion, and as the movement is transverse to the rack, which may be long and unwieldy, it is equally obvious that the cutting motion should be performed by the tools instead of the rack.

The feed adjustment of the tool being intermittent and the amount of cutting continually varying, this movement should be performed by hand, so as to be controlled at will by the sense of feeling. The same rule applies to the adjustment of the rack for spacing; being intermittent and irregular as to time, this movement should also be performed by hand. The speed of the cutting movement is known from ordinary practice to be from sixteen feet to twenty feet a minute, and a belt two and a half inches wide must move two hundred feet a minute to propel an ordinary metal cutting tool, so that the crank movement or cutter movement must be increased by gearing until a proper speed of the belt is reached; from this the speed of intermediate movers will be found.

Arrangement comes next; in this the first matter to be considered is convenience of manipulation. The cutting position should be so arranged as to admit of an easy inspection of the work. An operator having to keep his hand on the adjusting or feed mechanism, which is about twelve inches above the work, it follows that if the cutting level is four feet from the floor, and the feed handle five feet from the floor, the arrangement will be convenient for a standing position. As the work requires continual inspection and hand adjustments, it will for this reason be a proper arrangement to overhang both the supports for the rack and the cutting tools, placing them, as we may say, outside

the machine, to secure convenience of access and to allow of inspection. The position of the cutting bar, crank, connections, gearing, pulleys, and shafts, will assume their respective places from obvious conditions, mainly from the position of the operator and the work.

Next in order are strains. As the cutting action is the source of strains, and as the resistance offered by the cutting tools is as the length or width of the edges, it will be found in the present case that while other conditions thus far have pointed to small proportions, there is now a new one which calls for large proportions. In displacing the metal between teeth of three-quarters of an inch pitch, the cutting edge or the amount of surface acted upon is equal to a width of one inch and a half. It is true, the displacement may be small at each cut, but the strain is rather to be based upon the breadth of the acting edge than the actual displacement of metal, and we find here strains equal to the average duty of a large planing machine. This strain radiates from the cutting point as from a centre, falling on the supports of the work with a tendency to force it from the framing. Between the rack and the crank-shaft bearing, through the medium of the tool, cutter bar, connection, and crank pin, and in various directions and degrees, this strain may be followed by means of a simple diagram. Besides this cutting strain, there are none of importance; the tension of the belt, the side thrust in bearings, the strain from the angular thrust of the crank, and the end thrust of the tool, although not to be lost sight of, need not have much to do with problems of strength, proportion, and arrangement.

Strains suggest special arrangement, which is quite a distinct matter from general arrangement, the latter being governed mainly by the convenience of manipulation. Special arrangement deals with and determines the shape of framing, following the strains throughout a machine. In the present case we have a cutting strain which may be assumed as equal to one ton, exerted between the bracket or jaws which support the work, and the crank-shaft. It follows that between these two points the metal in the framing should be disposed in as direct a line as possible, and provision be made to resist flexion by deep sections parallel with the cutting motion.

Lastly, proportions; having estimated the cutting force required at one ton, although less than the actual strain in a

machine of this kind, we proceed upon this to fix proportions, beginning with the tool shank, and following back through the adjusting saddle, the cutting bar, connections, crank pins, shafts, and gear wheels to the belt. Starting again at the tool, or point of cutting, following through the supports of the rack, the jaws that clamp it, the saddle for the graduating adjustment, the connections with the main frame, and so on to the crank-shaft bearing a second time, dimensions may be fixed for each piece to withstand the strains without deflection or danger of breaking. Such proportions cannot, I am aware, be brought within the rules of ordinary practice by relying upon calculation alone to fix them, and no such course is suggested; calculation may aid, but cannot determine proportions in such cases; besides, symmetry, which cannot be altogether disregarded, modifies the form and sometimes the dimensions of various parts.

I have in this way imperfectly indicated a methodical plan of generating a design, as far as words alone will serve, beginning with certain premises based upon a particular work to be performed, and then proceeding to consider in consecutive order the general character of the machine, mode of operation, movements and adjustments, general arrangement, strains, special arrangement, and proportions.

With a thorough knowledge of practical machine operation, and an acquaintance with existing practice, an engineer proceeding upon such a plan, will, if he does not overlook some of the conditions, be able to generate designs which may remain without much modification or change, so long as the purpose to which the machinery is directed remains the same.

Perseverance is an important trait to be cultivated in first efforts at designing; it takes a certain amount of study to understand any branch of mechanism, no matter what natural capacity may be possessed by a learner. Mechanical operations are not learned intuitively, but are always surrounded by many peculiar conditions which must be learned *seriatim*, and it is only by an untiring perseverance at one thing that there can be any hope of improving it by new designs.

A learner who goes from gearing and shafts to steam and hydraulics, from machine tools to cranes and hoisting machinery, will not accomplish much. The best way is to select at first an easy subject, one that admits of a great range of modification, and if possible, one that has not assumed a standard form of

construction. Bearings and supports for shafts and spindles, is a good subject to begin with.

In designing supports for shafts the strains are easily defined and followed, while the vertical and lateral adjustment, lubrication of bearings, symmetry of supports and hangers, and so on, will furnish grounds for endless modification, both as to arrangement and mechanism.

In making designs it is best to employ no references except such as are carried in the memory. The more familiar a person is with machinery of any class, the more able he may be to prepare designs, but not by measuring and referring to other people's plans. Dimensions and arrangement from examples are, by such a course, unconsciously carried into a new drawing, even by the most skilled; besides, it is by no means a dignified matter to collect other people's plans, and by a little combination and modification produce new designs. It may be an easy plan to acquire a certain kind of proficiency, but will most certainly hinder an engineer from ever rising to the dignity of an original designer.

Symmetry, as an element in designs for machinery, is one of those unsettled matters which may be determined only in connection with particular cases; it may, however, be said that for all engineering implements and manufacturing machinery of every kind, there should be nothing added for ornament, or anything that has no connection with the functions of the machinery.

Modern engineers of the abler class are so thoroughly in accord in this matter of ornamentation, both in opinion and practice, that the subject hardly requires to be mentioned, and it will be no disadvantage for a learner to commence by cultivating a contempt for whatever has no useful purpose. Of existing practice it may be said, that in what may be called industrial machinery, the amount of ornamentation is inverse as the amount of engineering skill employed in preparing designs.

A safe rule will be to assume that machinery mainly used and seen by the skilled should be devoid of ornament, and that machinery seen mainly by the unskilled, or in public, should have some ornament. Steam fire engines, sewing machines, and works of a similar kind, which fall under the inspection of the unskilled, are usually arranged with more or less ornament.

As a rule, ornament should never be carried further than graceful proportions; the arrangement of framing should follow as nearly as possible the lines of strain. Extraneous decoration,

such as detached filagree work of iron, or painting in colours, is so repulsive to the taste of the true engineer and mechanic that it is unnecessary to speak against it.

(1.) Name some of the principal points to be kept in view in preparing designs?—(2.) Why should attempts at designing be confined to one class of machinery?—(3.) What objection exists to examining references when preparing designs?

CHAPTER XL.

INVENTION.

THE relation between invention and the engineering arts, and especially between invention and machines, will warrant a short review of the matter here; or even if this reason were wanting, there is a sufficient one in the fact that one of the first aims of an engineering apprentice is to invent something; and as the purpose here is, so far as the limits will permit, to say something upon each subject in which a beginner has an interest, invention must not be passed over.

It has been the object thus far to show that machines, processes, and mechanical manipulation generally may be systematised and generalised to a greater or less extent, and that a failure to reduce mechanical manipulation and machine construction to certain rules and principles can mainly be ascribed to our want of knowledge, and not to any inherent difficulty or condition which prevents such solution. The same proposition is applicable to invention, with the difference that invention, in its true sense, may admit of generalisation more readily than machine processes.

Invention, as applied to mechanical improvements, should not mean chance-discovery. Such a meaning is often, if not generally, attached to the term invention, yet it must be seen that results attained by a systematic course of reasoning or experimenting can have nothing to do with chance or even discovery. Such results partake more of the nature of demonstrations, a name peculiarly suitable for such inventions as are the result of methodical purpose

In such sciences as rest in any degree upon physical experiment, like chemistry, to experiment without some definite object may be a proper kind of research, and may in the future, as it has in the past, lead to great and useful results; but in mechanics the case is different; the demonstration of the conservation of force, and the relation between force and heat, have supplied the last link in a chain of principles which may be said to comprehend all that we are called upon to deal with in dynamical science, and there remains but little hope of developing anything new or useful by discovery alone. The time has been, and has not yet passed away, when even the most unskilled thought their ability to invent improvements in machinery equal with that of an engineer or skilled mechanic; but this is now changed; new schemes are weighed and tested by scientific standards, in many cases as reliable as actual experiments. A veil of mystery which ignorance of the physical sciences had in former times thrown around the mechanic arts, has been cleared away; chance discovery, or mechanical superstition, if the term may be allowed, has nearly disappeared. Many modern engineers regard their improvements in machinery as the exercise of their profession only, and hesitate about asking for protective grants to secure an exclusive use of that which another person might and often does demonstrate, as often as circumstances call for such improvement. There are of course new articles of manufacture to be discovered, and many improvements in machinery which may be proper subject matter for patent rights; improvements which in all chance would not be made for the term of a patent, except by the inventor; but such cases are rare; and it is fair to assume that unless an invention is one which could not have been regularly deduced from existing data, and one that would not in all probability have been made for a long term of years by any other person than the inventor, such an invention cannot in fairness become the property of an individual without infringing the rights of others.

It is not the intention to discuss patent law, nor even to estimate what benefits have in the past, or may in the future, be gained to technical industry by the patent system, but to impress engineering apprentices with a better and more dignified appreciation of their calling than to confound it with chance invention, and thereby destroy that confidence in positive results which has in the past characterised mechanical engineering; also to caution

learners against the loss of time and effort too often expended in searching after inventions.

It is well for an apprentice to invent or demonstrate all that he can—the more the better; but as explained in a previous place, what is attempted should be according to some system, and with a proper object. Time spent groping in the dark after something of which no definite conception has been formed, or for any object not to fill an ascertained want, is generally time lost. To demonstrate or invent, one should begin methodically, like a bricklayer builds a wall, as he mortars and sets each brick, so should an engineer qualify, by careful study, each piece or movement that is added to a mechanical structure, so that when done, the result may be useful and enduring.

As remarked, every attempt to generate anything new in machinery should be commenced by ascertaining a want of improvement. When such a want has been ascertained, attention should be directed first to the principles upon which such want or fault is to be remedied. Proper mechanism can then be supplied like the missing links in a chain. Propositions thus stated may fail to convey the meaning intended; this systematic plan of inventing may be better explained by an example.

Presuming the reader to remember what was said of steam hammers in another place, and to be familiar with the uses and general construction of such hammers, let it be supposed steam-hammers, with the ordinary automatic valve action, those that give an elastic or steam-cushioned blow, are well known. Suppose further that by analysing the blows given by hammers of this kind, it is demonstrated that dead blows, such as are given when a hammer comes to a full stop in striking, are more effectual in certain kinds of work, and that steam-hammers would be improved by operating on this dead-stroke principle.

Such a proposition would constitute the first stage of an invention by demonstrating a fault in existing hammers, and a want of certain functions which if added would make an improvement.

Proceeding from these premises, the first thing should be to examine the action of existing valve gear, to determine where this want of the dead-stroke function can best be supplied, and to gain the aid of such suggestions as existing mechanism may offer, also to see how far the appliances in use may become a part of any new arrangement.

By examining automatic hammers it will be found that their

valves are connected to the drop by means of links, producing coincident movement of the piston and valve, and that the movement of one is contingent upon and governed by the other. It will also be found that these connections or links are capable of extension, so as to alter the relative position of the piston and valve, thereby regulating the range of the blow, but that the movement of the two is reciprocal or in unison. Reasoning inductively, not discovering or inventing, it may be determined that to secure a stamp blow of a hammer-head, the valve must not open or admit steam beneath the piston until a blow is completed and the hammer has stopped.

At this point will occur one of those mechanical problems which requires what may be called logical solution. The valve must be moved by the drop; there is no other moving mechanism available; the valve and drop must besides be connected, to insure coincident action, yet the valve requires to move when the drop is still. Proceeding inductively, it is clear that a third agent must be introduced, some part moved by the drop, which will in turn move the valve, but this intermediate agent so arranged that it may continue to move after the hammer-drop has stopped.

This assumed, the scheme is complete, so far as the relative movement of the hammer-drop and the valve, but there must be some plan of giving motion to this added mechanism. In many examples there may be seen parts of machinery which continue in motion after the force which propels them has ceased to act; cannon balls are thrown for miles, the impelling force acting for a few feet only; a weaver's shuttle performs nearly its whole flight after the driver has stopped. In the present case, it is therefore evident that an independent or subsequent movement of the valves may be obtained by the momentum of some part set in motion during the descent of the hammer-head.

To sum up, it is supposed to have been determined by inductive reasoning, coupled with some knowledge of mechanics, that a steam hammer, to give a dead blow, requires the following conditions in the valve gearing:

1. That the drop and valve, while they must act relatively, cannot move in the same time, or in direct unison.

2. The connection between the hammer drop and valve cannot be positive, but must be broken during the descent of the drop.

3. The valve must move after the hammer stops.

4. To cause a movement of the valve after the hammer stops

there must be an intermediate agent, that will continue to act after the movement of the hammer drop has ceased.

5. The obvious means of attaining this independent movement of the valve gear, is by the momentum of some part set in motion by the hammer-drop, or by the force of gravity reacting on this auxiliary agent.

The invention is now complete, and as the principles are all within the scope of practical mechanism, there is nothing left to do but to devise such mechanical expedients as will carry out the principles laid down. This mechanical scheming is a second, and in some sense an independent part of machine improvement, and should always be subservient to principles; in fact, to separate mechanical scheming from principles, generally constitutes what has been called chance invention.

Referring again to the hammer problem, it will be found by examining the history that the makers of automatic-acting steam-hammers capable of giving the dead stamp blow, have employed the principle which has been described. Instead of employing the momentum, or the gravity of moving parts, to open the valve after the hammer stops, some engineers have depended upon disengaging valve gear by the concussion and jar of the blow, so that the valve gearing, or a portion of it, fell and opened the valve. The 'dead blow gear,' fitted to the earlier Nasmyth, or Wilson, hammers, was constructed on the latter plan, the valve spindle when disengaged being moved by a spring.

I will not consume space to explain the converse of this system of inventing, nor attempt to describe how a chance schemer would proceed to hunt after mechanical expedients to accomplish the valve movement in the example given.

Inventions in machine improvement, no matter what their nature, must of course consist in and conform to certain fixed modes of operating, and no plan of urging the truth of a proposition is so common, even with a chance inventor, as to trace out the 'principles' which govern his discovery.

In studying improvements with a view to practical gain, a learner can have no reasonable hope of accomplishing much in fields already gone over by able engineers, nor in demonstrating anything new in what may be called exhausted subjects, such as steam-engines or water-wheels; he should rather choose new and special subjects, but avoid schemes not in some degree confirmed by existing practice.

It has been already remarked that the boldness of young engineers is very apt to be inversely as their experience, not to say their want of knowledge, and it is only by a strong and determined effort towards conservatism, that a true balance is maintained in judging of new schemes.

The life of George Stephenson proves that notwithstanding the novelty and great importance of his improvements in steam transit, he did not "discover" these improvements. He did not discover that a floating embankment would carry a railway across Chat Moss, neither did he discover that the friction between the wheels of a locomotive and the rails would enable a train to be drawn by tractive power alone. Everything connected with his novel history shows that all of his improvements were founded upon a method of reasoning from principles and generally inductively. To say that he "discovered" our railway system, according to the ordinary construction of the term, would be to detract from his hard and well-earned reputation, and place him among a class of fortunate schemers, who can claim no place in the history of legitimate engineering.

Count Rumford did not by chance develope the philosophy of forces upon which we may say the whole science of dynamics now rests; he set out upon a methodical plan to demonstrate conceptions that were already matured in his mind, and to verify principles which he had assumed by inductive reasoning. The greater part of really good and substantial improvements, such as have performed any considerable part in developing modern mechanical engineering, have come through this course of first dealing with primary principles, instead of groping about blindly after mechanical expedients, and present circumstances point to a time not far distant when chance discovery will quite disappear.

(1.) What change has taken place in the meaning of the name "invention" as applied to machine improvement?—(2.) What should precede an attempt to invent or improve machinery?—(3.) In what sense should the name invention be applied to the works of such men as Bentham, Bodmer, or Stephenson?

CHAPTER XLI.

WORKSHOP EXPERIENCE.

To urge the necessity of learning practical fitting as a part of an engineering education is superfluous. A mechanical engineer who has not been "through the shop" can never expect to attain success, nor command the respect even of the most inferior workmen; without a power of influencing and controlling others, he is neither fitted to direct construction, nor to manage details of any kind connected with engineering industry. There is nothing that more provokes a feeling of resentment in the mind of a skilled man than to meet with those who have attempted to qualify themselves in the theoretical and commercial details of engineering work, and then assume to direct labour which they do not understand; nor is a skilled man long in detecting an engineer of this class; a dozen words in conversation upon any mechanical subject is generally enough to furnish a clue to the amount of practical knowledge possessed by the speaker.

As remarked in a previous place, no one can expect to prepare successful designs for machinery, who does not understand the details of its construction; he should know how each piece is moulded, forged, turned, planed, or bored, and the relative cost of these processes by the different methods which may be adopted.

An engineer may direct and control work without a knowledge of practical fitting, but such control is merely a commercial one, and cannot of course extend to mechanical details which are generally the vital part; the obedience that may thus be enforced in controlling others is not to be confounded with the respect which a superior knowledge of work commands.

A gain from learning practical fitting is the confidence which such knowledge inspires in either the direction of work or the preparation of plans for machinery. An engineer who hesitates in his plans for fear of criticism, or who does not feel a perfect confidence in them, will never achieve much success.

Improvements, which have totally changed machine fitting during thirty years past, have been of a character to dispense in a great measure with hand skill, and supplant it with what may be termed mental skill. The mere physical effect produced by a man's hands has steadily diminished in value, until it has now

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Improvements, which have totally changed machine fitting during thirty years past, have been of a character to dispense in a great measure with hand skill, and supplant it with what may be termed mental skill. The mere physical effect produced by a man's hands has steadily diminished in value, until it has now

or made a mistake, and when such inspection is thought to be prompted by curiosity only. The better plan in such cases is to ask permission to examine work in such a way that no one will hear the request except the person addressed; such an application generally will secure both consent and explanation.

Politeness is as indispensable to a learner in a machine shop as it is to a gentleman in society. The character of the courtesy may be modified to suit the circumstances and the person, but still it is courtesy. An apprentice may understand differential calculus, but a workman may understand how to bore a steam cylinder; and in the workman's estimation a problem in calculus is a trivial thing to understand compared with the boring of a steam engine cylinder. Under these circumstances, if a workman is not allowed to balance some of his knowledge against politeness, an apprentice is placed at a disadvantage.

Questions and answers constitute the principal medium for acquiring technical information, and engineering apprentices should carefully study the philosophy of questions and answers, just as he does the principles of machinery. Without the art of questioning but slow progress will be made in learning shop manipulation. A proper question is one which the person asked will understand, and the answer be understood when it is given; not an easy rule, but a correct one. The main point is to consider questions before they are asked; make them relevant to the work in hand, and not too many. To ask frequent questions, is to convey an impression that the answers are not considered, an inference which is certainly a fair one, if the questions relate to a subject demanding some consideration. If a man is asked one minute what diametrical pitch means, and the next minute how much cast iron shrinks in cooling, he is very apt to be disgusted, and think the second question not worth answering.

It is important, in asking questions, to consider the mood and present occupation of the person addressed; one question asked when a man's mind is not too much occupied, and when he is in a communicative humour, is worth a dozen questions asked when he is engaged, and not disposed to talk.

It is a matter of courtesy in the usages of a shop, and one of expediency to a learner, to ask questions from those who are presumed to be best informed on the subject to which the questions relate; and it is equally a matter of courtesy to ask questions of different workmen, being careful, however, never to

ask two different persons the same question, nor questions that may call out conflicting answers.

There is not a more generous or kindly feeling in the world than that with which a skilled mechanic will share his knowledge with those who have gained his esteem, and who he thinks merit and desire the aid that he can give.

An excellent plan to retain what is learned, is to make notes. There is nothing will assist the memory more in learning mechanics than to write down facts as they are learned, even if such memoranda are never referred to after they are made.

It is not intended to recommend writing down rules or tables relating to shop manipulation so much as facts which require remark or comment to impress them on the memory; writing notes not only assists in committing the subjects to memory, but cultivates a power of composing technical descriptions, a very necessary part of an engineering education. Specifications for engineering work are a most difficult kind of composition and may be made long, tedious, and irrelevant, or concise and lucid.

There are also a large number of conventional phrases and endless technicalities to be learned, and to write them will assist in committing them to memory and decide their orthography.

In making notes, as much as possible of what is written should be condensed into brief formulæ, a form of expression which is fast becoming the written language of machine shops. Reading formulæ is in a great degree a matter of habit, like studying mechanical drawings; that which at the beginning is a maze of complexity, after a time becomes intelligible and clear at a glance.

Upon entering the shop, a learner will generally, to use a shop phrase, "be introduced to a hammer and chisel;" he will, perhaps, regard these hand tools with a kind of contempt. Seeing other operations carried on by power, and the machines in charge of skilled men, he is likely to esteem chipping and filing as of but little importance and mainly intended for keeping apprentices employed. But long after, when a score of years has been added to his experience, the hammer, chisel, and file, will remain the most crucial test of his hand skill, and after learning to manipulate power tools of all kinds in the most thorough manner, a few blows with a chipping hammer, or a half-dozen strokes with a file, will not only be a more difficult test of skill, but one most likely to be met with.

To learn to chip and file is indispensable, if for no other purpose, to be able to judge of the proficiency of others or to instruct them. Chipping and filing are purely matters of han skill, tedious to learn, but when once acquired, are never forgotten. The use of a file is an interesting problem to study, and one of no little intricacy; in filing across a surface one inch wide, with a file twelve inches long, the pressure required at each end to guide it level may change at each stroke from nothing to twenty pounds or more; the nice sense of feeling which determines this is a matter of habit acquired by long practice. It is a wonder indeed that true surfaces can be made with a file, or even that a file can be used at all, except for rough work.

If asked for advice as to the most important object for an apprentice to aim at in beginning his fitting course, nine out of ten experienced men will say, "to do work well." As power is measured by force and velocity, work is measured by the two conditions of skill and time. The first consideration being, how well a thing may be done, and secondly, in how short a time may it be performed; the skill spent on a piece of work is the measure of its worth; if work is badly executed, it makes no difference how short the time of performance has been; this can add nothing to the value of what is done although the expense is diminished.

A learner is apt to reverse this proposition at the beginning, and place time before skill, but if he will note what passes around him, it will be seen that criticism is always first directed to the character of work performed. A manager does not ask a workman how long a time was consumed in preparing a piece of work until its character has been passed upon; in short, the quality of work is its mechanical standard, and the time consumed in preparing work is its commercial standard. A job is never properly done when the workman who performed it can see faults, and in machine fitting, as a rule, the best skill that can be applied is no more than the conditions call for; so that the first thing to be learned is to perform work well, and afterwards to perform it rapidly.

Good fitting is often not so much a question of skill as of the standard which a workman has fixed in his mind, and to which all that he does will more or less conform. If this standard is one of exactness and precision, all that is performed, whether it be filing, turning, planing, or drawing, will come to this standard. This faculty of mind can be defined no further than to say that

it is an aversion to whatever is imperfect, and a love for what is exact and precise. There is no faculty which has so much to do with success in mechanical pursuits, nor is there any trait more susceptible of cultivation. Methodical exactness, reasoning, and persistence are the powers which lead to proficiency in engineering pursuits.

There is, perhaps, no more fitting conclusion to these suggestions for apprentices than a word about health and strength. It was remarked in connection with the subject of drawing, that the powers of a mechanical engineer were to be measured by his education and mental abilities, no more than by his vitality and physical strength, a proposition which it will be well for an apprentice to keep in mind.

One not accustomed to manual labour will, after commencing, find his limbs aching, his hands sore; he will feel exhausted both at the beginning and at the end of a day's work. These are not dangerous symptoms. He has only to wait until his system is built up so as to sustain this new draught upon its resources, and until nature furnishes a power of endurance, which will in the end be a source of pride, and add a score of years to life. Have plenty of sleep, plenty of plain, substantial food, keep the skin clean and active, laugh at privations, and cultivate a spirit of self-sacrifice and a pride in endurance that will court the hardest and longest efforts. An apprentice who has not the spirit and firmness to endure physical labour, and adapt himself to the conditions of a workshop, should select some pursuit of a nature less aggressive than mechanical engineering.

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